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THE EASILY SOLUBLE PHOSPHORUS CONTENT OF SOIL AS DETERMINED BY ELECTRODIALYSIS, EXTRACTION WITH DILUTE ACID SOLUTIONS, AND CROP RESPONSE TO FERTILIZATION

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Although electrodialysis has been used by many different investigators, to study base exchange reactions in soil, very little information is available concerning the solubility of soil phosphates under the influence of the electric current and crop response to phosphorus fertilization. Cameron and Bell (4) studied the rate of solution of phosphorus in soil, using 5 gm. of soil and a 40-volt current, and found that phosphorus was slowly removed from soil by such treatment.

König, Hasenbaumer, and Glenk (7) studied the diffusion of phosphorus from soil placed on a parchment membrane and found that electrodialysis hastened the rate of removal of the phosphorus. Mattson (9) analyzed the dialyzate from certain soil colloids and found varying amounts of phosphorus in the cathode compartment. Rost (10) reports that electrodialysis is more important in detecting lime deficiency in soils than phosphorus deficiency. Only eight soils were studied. Humfeld (6) found that soil to which limestone, rock phosphate, and superphosphate had been added contained more easily soluble phosphorus, as determined by electrodialysis, than did untreated soil. Alben (1) studied the amount of phosphorus removed from two soils by electrodialysis and concluded that no correlation existed between the results obtained and the crop response from phosphorus fertilization. McGeorge and Breazeale (8) found that the removal of phosphorus from calcareous soils by electrodialysis correlated very well with phosphorus deficiency in one group of soils but did not correlate in a second group of soils where phosphorus availability was assumed to be the limiting factor in crop production.

If different kinds of phosphates exist in a soil and vary in their rate of solubility, electrodialysis should make it possible to study the rate of solution of soil phosphorus because the solute is quickly removed from the water film surrounding the soil particle and as a result more material will continue to go from the solid to the liquid phase. In previous investigations the number of samples which have been studied are hardly sufficient to give a very good index concerning the relation between the amount of phosphorus removed from soil by electrodialysis and response to phosphorus fertilization. Also it is quite possible that the time factor, or the voltage, or the amount of current which flows through the soil may have some effect on the results.

EXPERIMENTAL

In the following investigation several different phosphate minerals and a large number of soils were studied in order to determine whether or not electrodialysis could be used in measuring the rate of availability of soil phosphorus to plants. A comparison was made between the amount of phosphorus removed from soil by electrodialysis; the amount of available phosphorus as determined by the Bray method (3), the Truog method (11), and extraction with fifth normal sulfuric acid (5); and the response of crops to phosphorus fertilization.

The procedure which was used in the electrodialysis of the soil samples was as follows:

Ten grams of soil were placed between two strips of parchment paper in a cell similar to the one described by Mattson (9). The electrodes were made of platinum gauze and were approximately 2½ inches square. A current of 220 volts, regulated by placing a 50-watt lamp in the circuit, was used. One electrode was placed on each side of the soil sample, 200 cc. of distilled water was added to each side of the cell, and electrodialysis was continued for 3 hours. The solutions were removed from each cell at the end of the first 3-hour period, a second portion of distilled water was added to each compartment, and the dialysis was continued for a second 3-hour period. The solutions were changed against the end of the second 3-hour period and dialysis continued for a third period of approximately 15 hours. One hundred and fifty cubic centimeters of distilled water was placed in the anode chamber and 250 cc. of distilled water was placed in the cathode chamber at the beginning of the third period, since there was a gradual flow of water into the anode chamber as a result of electro-endosmosis and over a period of 15 hours a change of about 50 cc. occurred in these experiments. The solution which was removed from the cathode compartment was placed in a 250-cc. beaker, 5 cc. of concentrated nitric acid added, and the liquid evaporated to dryness. The residue was treated with 5 cc. of concentrated nitric acid and digested on a hot plate to destroy organic matter, which interferes with the colorimetric determination of phosphorus. This process was repeated if necessary. Although this treatment may be considered objectionable from the standpoint of measuring accurately the amount of inorganic phosphorus present in solution, it is well known that traces of organic acids will prevent or at least decrease the color produced in the molybdenum blue method for phosphorus; consequently the aforementioned procedure was used, since the error from organic phosphates should tend to approach a constant value and would not be as serious as a failure to obtain a test for inorganic phosphorus although it was present in the solution.

After the organic matter was removed, 5 to 10 cc. of concentrated nitric acid was added and the solution was digested at 90°C. for 10 to 15 minutes. Then 25 cc. of distilled water was added and digestion continued for 15 minutes. The solution was cooled, 5 drops of 0.1 per cent paranitrophenol was added, and the excess acid was neutralized with 1 to 1 ammonium hydroxide until a yellow color appeared. Then it was made slightly acid by the careful addition of nitric acid, containing 1 part of acid and 3 parts of water, the disappearance of the yellow color being used as an end point in the titration. After the solution was acidified it was made up to a volume of 100 cc. and an aliquot was removed for a phosphorus determination. The molybdenum blue method was used to determine the phosphorus when small amounts were present and the standard volumetric method was used when accurate results could not be obtained by the colorimetric method.

The Truog method for easily soluble phosphorus was used as recommended except that the sulfuric acid was not buffered to pH 3, since in most cases the pH of the filtrates varied from 3.0 to 5.6 after extraction. Further investigation also indicated that buffering the solution with potassium sulfate did not appreciably affect the amount of phosphorus removed from the soil.

The Bray method for available phosphorus was used as recommended.

The determination of the easily soluble phosphorus in soils by extraction with fifth normal sulfuric acid has been used in this laboratory for several years and has given very good results under Oklahoma conditions. Ten grams of soil is shaken intermittently with 100 cc. of fifth normal sulfuric acid for 20 minutes. The suspension is filtered and an aliquot, usually 5 cc., is diluted to 95 cc. with

distilled water. Then the phosphorus is determined by the molybdenum blue method as recommended by Atkins (2).

RESULTS OF INVESTIGATIONS

In order to determine the relation between the rate of solubility of phosphorus in different phosphate minerals, several different samples were obtained and the solubility of the phosphorus in these samples was determined by electrodialysis, 0.5 gm. of each mineral, which was ground to pass through a 100-mesh sieve, being used. Each sample was mixed thoroughly with 9.5 gm. of quartz sand and was dialyzed for three successive periods as explained under methods for the electrodialysis of soil. The results of this experiment are given in table 1.

TABLE 1

Rate of removal of phosphorus from mineral phosphates by electrodialysis

NUMBER	MINERAL	CHEMICAL FORMULA*	TOTAL PHOSPHORUS	TOTAL PHOSPHORUS REMOVED BY ELECTRODIALYSIS		
				3 hours	6 hours	21 hours
			per cent	*per cent*	*per cent*	*per cent*
1	Apatite	$Ca_3(PO_4)_2F$	16.41	10.14	20.17	41.37
2	Chlorapatite	$Ca_3(PO_4)_2Cl$	15.60	25.44	39.16	72.24
3	Collinsite	$(Ca_2(Mg,Fe)(PO_4)_2 \cdot 2\frac{1}{2}H_2O$	13.93	18.45	38.19	76.68
4	Collophanite	$Ca_3(PO_4)_2 \cdot H_2O$	13.50	12.94	30.34	71.19
5	Dufrenite	$FePO_4 \cdot Fe(OH)_3$	2.54	7.40	11.41	14.64
6	Griphite	$(Mn,Ca,Na_2)O \cdot Al_3(PO_4)_2 \cdot H_2O$	14.42	15.73	35.83	71.31
7	Quercyite	$Ca_3(PO_4)_2 \cdot x\ H_2O$	14.31	9.84	24.29	59.19
8	Triplite	$(Mn,Fe)PO_4 \cdot F$†	11.34	8.81	20.08	45.46
9	Variscite	$AlPO_4 \cdot 2H_2O$	14.63	3.00	5.67	8.60
10	Vivianite	$Fe_3(PO_4)_2 \cdot 8H_2O$	12.31	1.54	2.10	3.89
11	Wavellite	$Al_3(OH)_3(PO_4)_2 \cdot 4\frac{1}{2}H_2O$	9.45	1.53	3.12	5.85

* Minerals were obtained from Ward's Natural Science Establishment, Rochester, New York.

† Some Ca and Mg usually present.

The amount of phosphorus removed from chlorapatite, collinsite, and collophanite, which are calcium phosphate minerals, was much higher than the amount of phosphorus removed from the iron and aluminum phosphates, dufrenite, variscite, vivianite, and wavellite. Three samples were in an intermediate group. They were apatite, quercyite, and triplite. The quercyite contained much organic matter, which may have accounted for the low results with this particular mineral.

If certain soils contained the major portion of their phosphorus in the form of iron or aluminum phosphate, less phosphorus should be extracted from these soils than from soils which contained a major portion of their phosphorus in the form of calcium or magnesium phosphate. Also if a soil contained only a small portion of its available phosphorus in the form of calcium phosphate, it

TABLE 2

Source of soil samples used in this investigation

SOIL NUMBER	LOCATION	EXPERIMENT OR PLOT NUMBER
69	Sapulpa, Okla.	Cotton Fertility Study, Outfield Station
93	Poteau, Okla.	Cotton Fertility Study, County Fair Ground
95	Chandler, Okla.	Sweet Clover Experiment, Frank Carpenter Farm
102	Durant, Okla.	Cotton Fertility Study, Outfield Station
103	Purcell, Okla.	Cotton Fertility Study, Outfield Station
106	Eufaula, Okla.	Rotation Experiments, Outfield Station
118	Stillwater, Okla.	Plot 6205, Experiment Station Farm
136	Stillwater, Okla.	Manured Wheat, Field "O"
137	Stillwater, Okla.	Unmanured Wheat, Field "O"
210	Tifton, Ga.	Cotton Fertility Experiment
334	Purcell, Okla.	Cotton Fertility Experiment, H. E. Perkinson Farm
348	Harrah, Okla.	Cotton Fertility Experiment, W. M. Pace Farm
445	Orlando, Okla.	Alfalfa Fertility Experiment, W. D. Thedford Farm
447	Ralston, Okla.	Alfalfa Fertility Experiment, J. W. Chase Farm
449	Statesville, N. C.	Plot 5, Field B, Fertilizer Experiment on Cotton
450	Stillwater, Okla.	Lewis Field Cotton Experiment, 1927
452	Stigler, Okla.	Sweet Clover Experiment, Blankenship Farm
470	Shawnee, Okla.	Cotton Fertility Experiment, John Price (tenant)
477	Kingston, R. I.	Plot 67N, R. I. Agr. Exp. Station
478	Lincoln, Neb.	Plot 442, Neb. Agr. Exp. Station
479	Scotts Bluff, Neb.	Plot 3411, Scotts Bluff Agr. Exp. Station
482	Scotts, Ark.	Fertility Experiments, Arkansas Agr. Exp. Substation
483	Fayetteville, Ark.	Sect. 24, Rotation Experiments, Arkansas Agr. Exp. Sta.
486	Raleigh, N. C.	Cecil Clay Loam, N. C. Agr. Exp. Station
487	Greenville, Ky.	Plot 310, Kentucky Agr. Exp. Substation
488	Lexington, Ky.	Plot 203, Kentucky Agr. Exp. Station
489	Beeville, Texas	T 31–40, Texas Agr. Exp. Substation No. 1
490	Angleton, Texas	Lake Charles Clay, Texas Agr. Exp. Substation
491	College Station, Texas	Plot 43, Texas Agr. Exp. Station
492	Paulding, Ohio	Plot 7, Block C, Rotation I, Ohio Agr. Exp. Substation
493	Wooster, Ohio	Plot 10 W, Section D, 5-yr. Rotation, Ohio Agr. Exp. Station
498	Joliet, Ill.	Plot 407, Ill. Agr. Exp. Field Station
500	Columbia, Mo.	Plot 9, Sanborn Field, Mo. Agr. Exp. Station
501	Manhattan, Kans.	Plot 2, Series 2, Kan. Agr. Exp. Station
503	New Brunswick, N. J.	Plot 7 A. N. J. Agr. Exp. Station
504	Bedford, Ind.	Indiana Agr. Exp. Substation
505	Lafayette, Ind.	Indiana Agr. Exp. Substation
506	Hennessey, Okla.	Wheat Fertility Experiment, Art. Ulmark Farm
507	Fairmont, Okla.	Wheat Fertility Experiment, Clarence Niehus Farm
513	Stigler, Okla.	Fertility Experiments on Corn and Cotton, P. E. McDaniel Farm
616	Perry, Okla.	Alfalfa Fertility Experiment, J. H. Dolezal Farm
663	Carrier, Okla.	Wheat Fertility Experiment, A. E. Ford Farm
703	Keosanqua, Ia.	Plot 1, Outfield Experiments, Iowa Agr. Exp. Station
707	Waverly, Iowa	Field No. II, Plot 1, Outfield Exps. Ia. Agr. Exp. Station
708	Calamus, Ia.	Plot 10, Outfield Experiments, Ia. Agr. Exp. Station

TABLE 2—*Concluded*

SOIL NUMBER	LOCATION	EXPERIMENT OR PLOT NUMBER
712	Ames, Iowa	Plot 1310, Iowa Agr. Exp. Station
712	Ames, Iowa	Plot 1000, Iowa Agr. Exp. Station
722	Granite, Okla.	Wheat Fertility, Exp. Plot 10, Okla. Agr. Exp. Substation
732	Glencoe, Okla.	Sweet Clover Fertility Experiment, J. Waltermire Farm
733	Columbus, Kans.	Plot 1 F, Kansas Agr. Exp. Substation
735	Moran, Kans.	Plot 1 A, Kansas Agr. Exp. Substation
737	Lenapah, Okla.	Pasture Fertility Experiment, Norman Mounce Farm
749	Granite, Okla.	Cotton Fertility Experiment, S. W. Parr Farm
750	Granite, Okla.	Cotton Fertility Experiment, Okla. Agr. Exp. Substation
754	Drumright, Okla.	Alfalfa Fertility Experiment, James Salisbury Farm
762	Stillwater, Okla.	Alfalfa Fertility Experiment, Range 1110 Okla. Agr. Exp. Sta.
790	Stillwater, Okla.	Alfalfa Fertility Experiment, Snowden Farm
797	Jennings, Okla.	Alfalfa Fertility Experiment, Carl Harbison Farm
858	Lovell, Okla.	Wheat Fertility Exp., C. L. Terhune Farm
862	Garber, Okla.	Wheat Fertility Exp., Rollie Kingery Farm
865	Waukomis, Okla.	Wheat Fertility Exp., Oscar Winchester Farm
894	Neodesha, Okla.	Fertility Experiments, W. O. Rittenhouse Farm
927	Goodwell, Okla.	Panhandle Agr. Exp. Station
962	Marianna, Ark.	Arkansas Agr. Exp. Substation
992	Union, Okla.	Fertility Experiments, Joseph Roy Farm
1032	Mulhall, Okla.	Cotton Fertility Experiments, Lincoln Lewis Farm
1044	Coweta, Okla.	Fertility Experiments, T. R. Stone Farm
P 1	Deer Creek, Okla.	Sweet Clover Fertility Experiment, M. C. Lichti Farm
P 8	Perry, Okla.	Sweet Clover Fertility Experiment, F. J. Blecha Farm
P 15	Perry, Okla.	Sweet Clover Fertility Experiment, C. J. Wallerstedt Farm
P 29	Deer Creek, Okla.	Sweet Clover Fertility Experiment, Emil Dester Farm
P 36	Chandler, Okla.	Sweet Clover Fertility Experiment, Lincoln County Farm
P 43	Okemah, Okla.	Sweet Clover Fertility Experiment, V. W. Miracle Farm
P 50	Perkins, Okla.	Sweet Clover Fertility Experiment, George Kirk Farm
P 57	Morris, Okla.	Sweet Clover Fertility Experiment, Morton & Hathaway Farm
P 64	Checotah, Okla.	Sweet Clover Fertility Experiment, Roy Nichols Farm
P 69	Mulhall, Okla.	Sweet Clover Fertility Experiment, Cleve Martin Farm
P 76	Neodesha, Okla.	Sweet Clover Fertility Experiment, W. O. Rittenhouse Farm
P 83	Beggs, Okla.	Sweet Clover Fertility Experiment, F. E. Wilson Farm
P 90	Guthrie, Okla.	Sweet Clover Fertility Experiment, H. L. Morrissett Farm
P 206	Duncan, Okla.	Sweet Clover Fertility Experiment, L. A. Morton Farm
P 216	Pawnee, Okla.	Sweet Clover Fertility Experiment, Stanley Dugan Farm
P 222	Pawnee, Okla.	Sweet Clover Fertility Experiment, L. F. Crocker Farm

would be removed in a short time and then the amount of phosphorus extracted would decrease very rapidly as the electrodialysis was continued.

In order to determine the variation in the amount of easily soluble phosphorus extracted from different soils, 83 different samples of soil were studied. These soils were obtained from unfertilized plots from fertility experiments, conducted in Oklahoma and in several other different places in the United States. The location from which each sample was obtained and the plot number or nature of the experiment are given in table 2. All of the samples in table 2 were analyzed for available phosphorus by electrodialysis, three successive extractions, as explained under methods of analysis, being used. Since the results from these extractions indicated that soils contain a certain portion of their phosphorus which is present in a readily available form, only the data

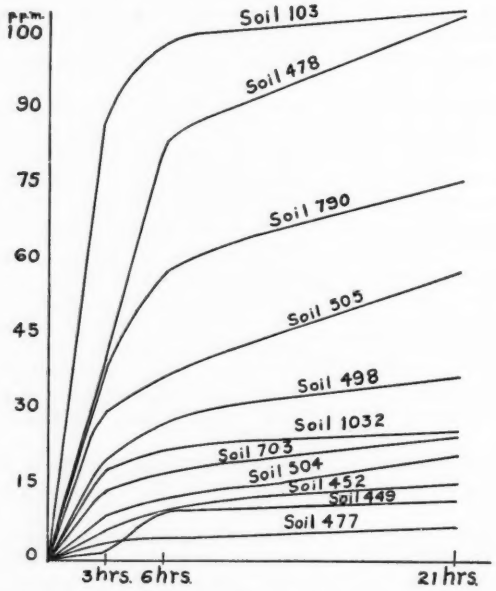


FIG. 1. SOLUBILITY CURVES OF SOIL PHOSPHORUS EXTRACTED BY ELECTRODIALYSIS

from a few representative samples are presented in figure 1. In all cases except one the amount of phosphorus extracted by electrodialysis during the first 3-hour period is larger than the amount extracted during the second and third 3-hour period. Soil 449 yielded more phosphorus in the second 3-hour period than it did in the first 3-hour period. However the amount of phosphorus removed from this soil was very low and it would have no influence on the recommendation which would be made concerning the need of this particular soil for phosphorus fertilization.

The comparison between the amount of phosphorus extracted by electrodialysis for a 3-hour period and the amount of phosphorus removed by three

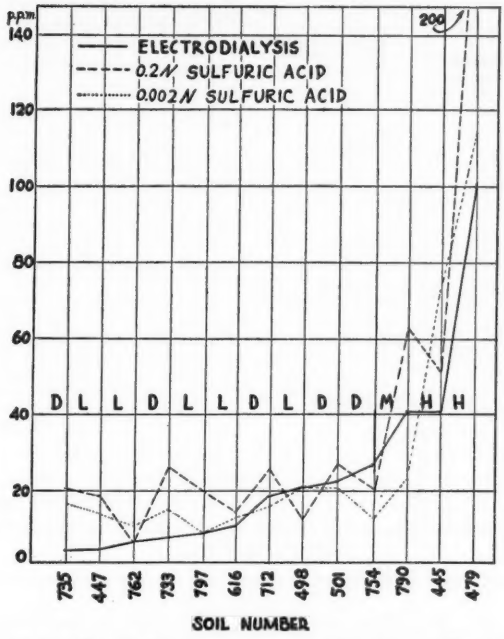


FIG. 2. STUDIES ON THE EASILY SOLUBLE PHOSPHORUS CONTENT OF SOIL AS DETERMINED BY ELECTRODIALYSIS, SULFURIC ACID EXTRACTION, AND THE BRAY TEST, AS COMPARED WITH THE RESPONSE FROM FIELD EXPERIMENTS WITH PHOSPHATE FERTILIZERS APPLIED TO ALFALFA

The first 10 soils beginning at the left respond to phosphorus fertilization

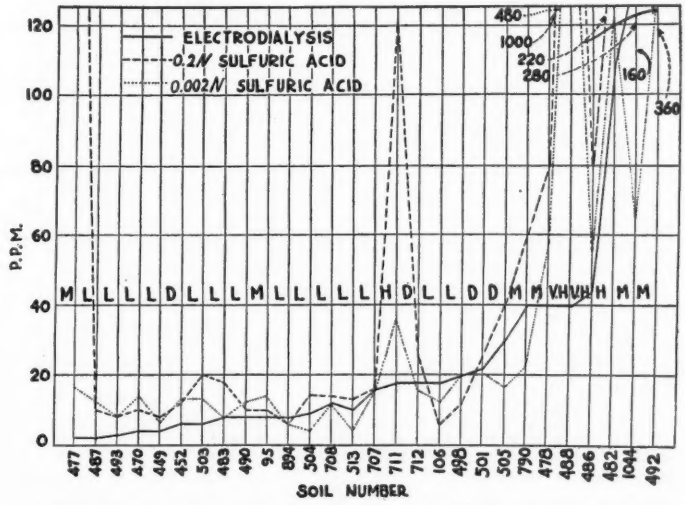


FIG. 3. STUDIES ON THE EASILY SOLUBLE PHOSPHORUS CONTENT OF SOIL AS DETERMINED BY ELECTRODIALYSIS, SULFURIC ACID EXTRACTION AND THE BRAY TEST, AS COMPARED WITH THE RESPONSE FROM FIELD EXPERIMENTS WITH PHOSPHATE FERTILIZERS APPLIED TO CORN

The first 19 soils beginning at the left respond to phosphorus fertilization

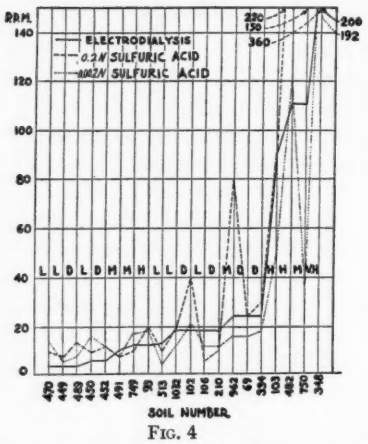


FIG. 4

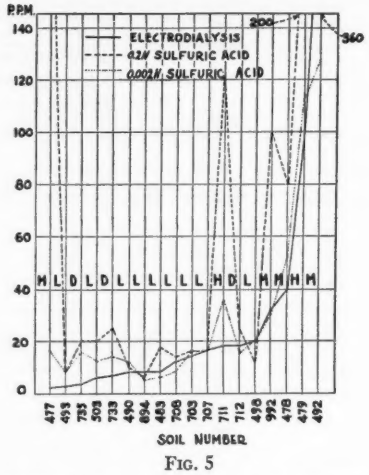


FIG. 5

FIG. 4. STUDIES ON THE EASILY SOLUBLE PHOSPHORUS CONTENT OF SOIL AS DETERMINED BY ELECTRODIALYSIS, SULFURIC ACID EXTRACTION, AND THE BRAY TEST, AS COMPARED WITH THE RESPONSE FROM FIELD EXPERIMENTS WITH PHOSPHATE FERTILIZERS APPLIED TO COTTON

The first 13 soils beginning at the left, except soil 491, respond to phosphorus fertilization

FIG. 5. STUDIES ON THE EASILY SOLUBLE PHOSPHORUS CONTENT OF SOIL AS DETERMINED BY ELECTRODIALYSIS, SULFURIC ACID EXTRACTION, AND THE BRAY TEST, AS COMPARED WITH THE RESPONSE FROM FIELD EXPERIMENTS WITH PHOSPHATE FERTILIZERS APPLIED TO OATS

The first 14 soils beginning at the left respond to phosphorus fertilization

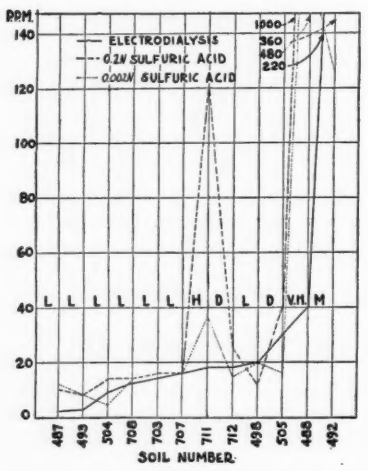


FIG. 6

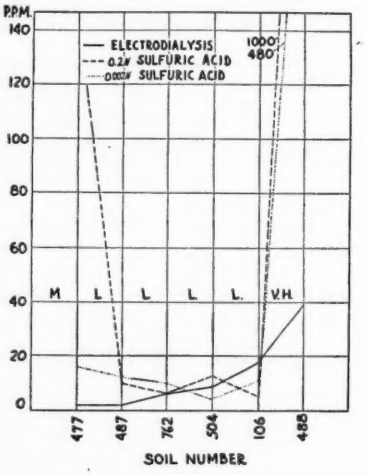


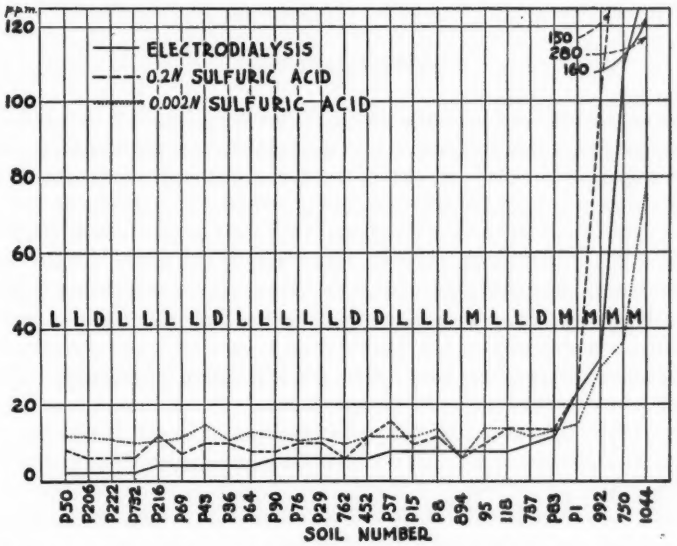
FIG. 7

FIG. 6. STUDIES ON THE EASILY SOLUBLE PHOSPHORUS CONTENT OF SOIL AS DETERMINED BY ELECTRODIALYSIS, SULFURIC ACID EXTRACTION AND THE BRAY TEST, AS COMPARED WITH THE RESPONSE FROM FIELD EXPERIMENTS WITH PHOSPHATE FERTILIZERS APPLIED TO RED CLOVER

The first 9 soils beginning at the left respond to phosphorus fertilization

FIG. 7. STUDIES ON THE EASILY SOLUBLE PHOSPHORUS CONTENT OF SOIL AS DETERMINED BY ELECTRODIALYSIS, SULFURIC ACID EXTRACTION, AND THE BRAY TEST, AS COMPARED WITH THE RESPONSE FROM FIELD EXPERIMENTS WITH PHOSPHATE FERTILIZERS APPLIED TO SOYBEANS

The first 5 soils beginning at the left respond to phosphorus fertilization


PPM
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100
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0.002N SULFURIC ACID
150
280
160
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P50 P206 P222 P732 P216 P69 P43 P36 P64 P90 P76 P29 762 452 P57 P15 P8 894 95 118 737 P83 P1 992 750 1044
SOIL NUMBER

FIG. 8. STUDIES ON THE EASILY SOLUBLE PHOSPHORUS CONTENT OF SOIL AS DETERMINED BY ELECTRODIALYSIS, SULFURIC ACID EXTRACTION AND THE BRAY TEST, AS COMPARED WITH THE RESPONSE FROM FIELD EXPERIMENTS WITH PHOSPHATE FERTILIZERS APPLIED TO SWEET CLOVER

All soils respond to phosphorus fertilization except the last four on the right

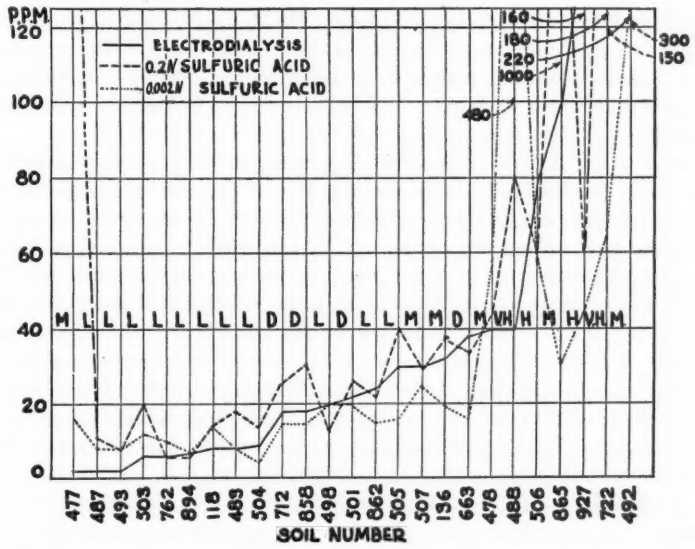

FIG. 9. STUDIES ON THE EASILY SOLUBLE PHOSPHORUS CONTENT OF SOIL AS DETERMINED BY ELECTRODIALYSIS, SULFURIC ACID EXTRACTION, AND THE BRAY TEST, AS COMPARED WITH THE RESPONSE FROM FIELD EXPERIMENTS WITH PHOSPHATE FERTILIZERS APPLIED TO WHEAT

The first 15 soils beginning at the left, except soils 858, 501, and 862, respond to phosphorus fertilization.

different methods of acid extraction is presented in figures 2 to 9 inclusive. The crops which were studied in connection with this investigation were alfalfa, corn, cotton, oats, red clover, soybeans, sweet clover, and wheat. The results obtained from some of the soils occur in three or four different charts; however because of the variation in crops grown in different rotations and in different parts of the United States, and since many samples of soil were obtained from experimental plots where only one crop such as cotton, wheat or alfalfa was being grown, it was necessary to compare the data showing the response obtained from phosphorus fertilizers applied to each crop with the amount of phosphorus removed from each soil by the four different laboratory methods which were described in a previous paragraph.

In all cases the amount of phosphorus removed by electrodialysis was used as a basis for comparison. The results obtained by the Bray test are recorded on the charts as follows: L = Low, D = Doubtful, M = Medium, H = High, VH = Very High. Those soils which respond to phosphorus fertilization are indicated in the legend of each figure.

CORRELATION STUDIES

Alfalfa. The results of soil analysis and crop response to phosphorus fertilization on alfalfa are given in figure 2. Soils which contained more than 30 p.p.m. of easily soluble phosphorus as determined by electrodialysis and 0.2 *N* sulfuric acid extraction and more than 20 p.p.m. by the Truog method did not respond to phosphorus fertilization. All of the soils which contained less than these amounts responded to phosphorus fertilization. Fifty per cent of the soils which responded to fertilization tested doubtful by the Bray method.

Corn. The results comparing the amount of easily soluble phosphorus extracted from soil and crop response from fertilizers applied to corn are shown in figure 3. In this particular experiment the agreement between the different methods was very good except that the 0.2 *N* sulfuric acid method and the Bray method extracted considerable amounts of phosphorus from soil 477. This soil contains a large amount of easily soluble iron phosphate, which apparently is not readily available for plants. All of the methods except electrodialysis gave high results on soil 711, which is a calcareous soil obtained from the Iowa Agricultural Experiment Station and probably contains considerable amounts of occluded phosphate. Soils which contained less than 20 or 30 p.p.m. of easily soluble phosphorus responded to phosphorus fertilizers applied to corn.

Because of a marked variation in climatic and soil conditions in different parts of the country, it may be difficult to determine the amount of easily soluble phosphorus above which crop response from phosphorus fertilization would not be obtained and below which response from fertilization will be profitable. In the Great Plains area very frequently drouth is a limiting factor in crop production even on soils which are deficient in phosphorus.

Also Truog (11) has pointed out that corn grown in the northern climates may need larger amounts of easily soluble phosphorus than corn grown in the Southern States because of the difference in the length of the growing season. Another factor which is also important is the amount of organic phosphorus which is liberated by biological activities in the soil.

Cotton. The three quantitative methods showed a very good correlation for easily soluble phosphorus and response from phosphorus fertilizers applied to cotton. Only one soil which was very low in easily soluble phosphorus did not respond to phosphorus fertilization. This soil was number 491 and came from College Station, Texas. On this particular soil, nitrogen is an important limiting factor in crop production.

The results obtained by the Bray test were either doubtful, medium, or high in 7 out of the 13 soils which responded to phosphorus fertilization. Also the amount of phosphorus extracted by the Truog method was rather low on the three samples of soil which did not respond to phosphorus fertilization. Soil 102 is a black waxy soil which is basic in reaction, and response from phosphorus fertilization was slight.

In comparing the results obtained from fertilizers applied to cotton and the amount of easily soluble phosphorus in the soil, it should be kept in mind that very frequently fertilizers which are applied to cotton are in all probability not applied in the ratio which will give maximum results from the standpoint of economical fertilization, especially when low and high rates of fertilization are compared. Many experiments conducted on phosphorus deficient soils indicate that the addition of a complete fertilizer will continue to give an increase in crop yield as the rate of fertilization is increased. Most experiments, however, are not designed to show which plant food is responsible for the increase in yield. It is quite possible that many soils which have been fertilized for a long time contain enough easily soluble phosphorus to produce good yields and that the effect of the addition of a complete fertilizer on the growth of plants is due to the nitrogen and potash applied. Although phosphorus is not an expensive fertilizer, there are many soils where the percentage of phosphorus in the fertilizer could be reduced considerably or eliminated completely for a while, because of the residual accumulation of phosphorus from previous treatments.

Oats. The data obtained on oats are very similar to the results presented on corn. Soil 477 and soil 711 also occurred in this comparison. The zone above which no response from phosphorus fertilization was obtained was somewhere between 20 and 30 p.p.m. of easily soluble phosphorus in the soil.

Red Clover. The results of comparing the easily soluble phosphorus content of soil and the response from phosphorus fertilizers applied to red clover give no information different from that obtained from previous charts. Soil 711 does not correlate very well with the response from phosphorus fertilization except by electrodialysis. Also the Truog method did not extract enough phosphorus from soil 505 to differentiate it from soils which do not respond to phosphorus fertilization.

Soybeans. Only six samples of soil were studied in the case of soybeans, and consequently from the few data presented accurate conclusions cannot be drawn. Soil 488, which came from the experimental plots at Lexington, Kentucky, was very high in easily soluble phosphorus except by electrodialysis, which would indicate that much of the phosphorus in this soil is occluded but can be extracted by dilute acid solutions.

Sweet Clover. All of the samples used in this study were from Oklahoma. A very good agreement occurred in all of the quantitative tests for easily soluble phosphorus, but the Bray method was doubtful or medium on six soils where marked response resulted from phosphorus fertilization. Sweet clover is a very vigorous feeder on soil phosphate, and although it gives a marked response to phosphorus fertilization it will also make a very good growth on soils which

TABLE 3

The accuracy of different methods for determining the easily soluble phosphorus in soils as compared with response from phosphorus fertilization

NUMBER	CROP	NUMBER OF SAMPLES	NUMBER OF SAMPLES IN AGREEMENT WITH RESPONSE FROM PHOSPHORUS FERTILIZATION BY:			
			Electro-dialysis	Truog method	Bray method	Extraction with 0.2 *N* sulfuric acid
1	Alfalfa	13	13	12	8	13
2	Corn	28	27	24	21	25
3	Cotton	20	18	16	10	17
4	Oats	18	18	17	13	15
5	Red Clover	12	11	10	9	11
6	Soybeans	6	6	6	5	5
7	Sweet Clover	26	26	25	20	26
8	Wheat	25	21	19	20	21
Total number of comparisons		148	140	129	106	133
Per cent agreement		...	94.5	87.1	71.6	89.8

contain rather small amounts of easily soluble phosphorus provided the soil is not too acid. From figure 8 it is quite evident that most of the soils were rather deficient in easily soluble phosphorus or else contained an abundance of this particular plant food; consequently there is a lack of definite information concerning soils which contain from 30 to 50 p.p.m. of easily soluble phosphorus.

Wheat. The correlations between the effect of phosphorus fertilizers applied to wheat and the easily soluble phosphorus content of soils as determined by the different methods are very erratic. Since winter wheat is frequently affected by climatic conditions, which may reduce the yield of this crop even though it is grown on good soils, and also since wheat needs an abundance of available nitrogen to produce a good yield, it is entirely possible that phos-

phorus has not always been the most important limiting factor in many of the experiments from which the soil samples were taken.

All Crops. The results of the correlation between the response from phosphorus fertilizers applied to eight different crops and the amount of easily soluble phosphorus extracted from the soils on which these crops were grown are presented in table 3. Since electrodialysis is not a method which is well adapted to the average laboratory, apparently the Truog method or the 0.2 *N* sulfuric acid extraction method can be recommended for noncalcareous soils. Where large amounts of easily soluble ferric or aluminum phosphate are present in the soil, the Truog method is more accurate than results from 0.2 *N* sulfuric extraction. The chief difficulty with the Truog method is that it does not remove enough phosphorus from some soils which do not respond to phosphorus fertilization so that they can be separated from those which do respond to an application of phosphate fertilizer. Recent investigation has indicated that leaching a soil with 0.1 *N* acetic acid is the most accurate method for differentiating between non calcareous or slightly calcareous soils which respond or do not respond to phosphorus fertilization. The results of these experiments will be published in another paper.

DISCUSSION

Truog (11) has suggested that most of the phosphorus in a soil was probably present either in the form of iron or calcium phosphate. Since dilute acid solutions readily dissolve calcium phosphate, only small amounts of this material should be present in those soils which respond to phosphorus fertilization. When soils which contain small amounts of easily soluble phosphorus do not respond to phosphorus fertilization they either are high in total organic matter or contain fresh organic matter which supplies enough available phosphorus as a result of the mineralization of the organic matter to meet the needs of the growing crop.

In studying the method by which plants feed, we find that the root hairs probably do not extract phosphorus from one particular point for a very long time, not to exceed 10 or 12 days in most cases; consequently when one group of root hairs perish a certain interval occurs during which no roots appear in that particular zone. In case of extraction methods or electrodialysis, all of the phosphorus which is exposed on the surface of the soil particles is attacked by the solvent. In the case of plants, only a limited number of the phosphorus particles occurring in the soil are in contact with the root hairs; consequently the distribution of the root system combined with the feeding power of plants is an important factor in determining the amount of phosphorus which different plants will extract from any particular soil, and this factor may affect in some instances the lack of correlation between field results and chemical methods for determining phosphorus availability.

In studying the results obtained by the Bray method, it was found that many of the soils which respond to phosphorus fertilization actually give

medium values and frequently give values which are classified as high from the standpoint of easily soluble phosphorus. Further investigation indicated that this difficulty was frequently caused by a lack of easily soluble iron in those particular soils. In case of soils which have considerable amounts of easily soluble iron and small amounts of easily soluble phosphorus, the presence of sufficient iron in the solution prevents the maximum development of the molybdenum blue color when the test is made. However when a soil contains small amounts of easily soluble iron and also only a small amount of easily soluble phosphorus, a blue color will appear because of the fact that there is not enough iron present in the solution to prevent the development of the blue color when the tin rod is placed in the clear soil extract. It would be better to use a weak acid solution to extract the soil and then add the ammonium molybdate reagent to the soil extract, after which the blue color could be developed by stirring the clear filtrate with a tin rod. Under such conditions the effect of the iron would be eliminated and the test would be more accurate.

Acetic acid or a buffered solution of sodium acetate is not entirely satisfactory for use in extracting the easily soluble phosphorus from soil because of the possibility of decomposition of these solutions by molds. A dilute solution of sulfuric acid can be used, or the acetic acid can be preserved by adding 5 p.p.m. of mercuric chloride, which does not interfere with the test. Truog has pointed out that very little iron is dissolved by acid solutions higher than pH 3. In this experiment, soil 477, which came from the Rhode Island Agricultural Experiment Station, was very high in easily soluble iron. It was found that very little iron was dissolved from this soil when the pH of the extracting medium was above 2.7. About ten thousand samples of soil have been studied in this laboratory, and none of them were as high in easily soluble iron as this sample. It is quite likely that any method which involves the use of an acid solution to determine the easily soluble phosphorus content of soils should be less acid than 2.7, especially when large amounts of easily soluble iron or large amounts of ferric or aluminum phosphate are present in the soil. In most of the soils studied the amount of easily soluble iron or easily soluble ferric or aluminum phosphate was very low, since relatively small amounts were dissolved by 0.2 *N* sulfuric acid, which has a pH of less than 1.

From a study of these results it appears that in most soils the amounts of easily soluble phosphorus compounds are relative and that under favorable conditions practically any of these quantitative methods will give a very good index of the availability of phosphorus to plants; although the more dilute acid solutions are preferable under certain conditions.

One of the objections to electrodialysis is that it removes all of the products of solution, which in some instances if left in the soil might depress the solubility of the phosphate ion. Leaching methods are open to the same criticism. In extraction methods the dissolved salts remain in contact with the soil and in some instances the equilibrium between the soluble phosphorus which occurs in the soil extract and that portion which is held or reprecipitated on the sur-

face of certain soil particles may not give a good index concerning the amount of phosphorus which may be dissolved by the root hairs acting upon a small percentage of the phosphate particles which occur in the soil.

SUMMARY

A study was made to compare the amount of phosphorus removed from soil by electrodialysis and dilute acid solutions with the response obtained from phosphorus fertilization. Eighty-three soils were obtained from different soil fertility experiments conducted in Oklahoma and in other parts of the United States.

A large percentage of the easily soluble phosphorus occurring in the average soil was removed in a 3-hour extraction by electrodialysis. A close correlation occurred between the amount of phosphorus removed by electrodialysis and the response of crops to phosphorus fertilization.

A graphical presentation was made of the data compared with fertilizer response from eight different crops: alfalfa, corn, cotton, oats, red clover, soybeans, sweet clover, and wheat.

In most cases soils which contain more than 30 p.p.m. of easily soluble phosphorus do not respond to phosphorus fertilization. In the case of the Truog method, very few soils produced a marked response from phosphorus fertilization when the easily soluble phosphorus was above 20 p.p.m. The Bray method for easily soluble phosphorus was not as accurate as the other quantitative methods. It was found that a lack of easily soluble iron in the soil was frequently responsible for the appearance of doubtful and medium amounts of easily soluble phosphorus by the Bray test when certain soils which give a marked response to phosphorus fertilization were analyzed.

The rate of solubility of different phosphate minerals by electrodialysis was studied. It was found that the iron and aluminum phosphates were less soluble than the calcium phosphates. Apatite, triplite, and quercyite were less soluble than chlorapatite, collinsite, collophanite, and griphite. Dufrenite, wavellite, and vivianite were the least soluble of the minerals studied.

Very little iron is dissolved from soils by solutions which are less acid than pH 2.7.

Climatic conditions are frequently interfering factors from the standpoint of determining response of soils to phosphorus fertilization as compared with the amount of easily soluble phosphorus present in the soil. Also soils which contain large amounts of organic matter may be rather low in easily soluble phosphorus, but little response is obtained from phosphorus fertilization, since enough of this element is obtained by the plant as a result of the mineralization of organic phosphorus by the bacteria and fungi in the soil.

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ESTIMATION OF PLANT AVAILABLE PHOSPHATE IN SOIL

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After some years of study and of experimenting with methods, the writer has developed procedures which appear to give as nearly as possible, with present knowledge, a fairly reliable estimate of the amount of phosphate easily available to plants in a soil. Much remains to be done before the results of examination of a soil can be interpreted with satisfactory reliability, yet the results already obtained are deemed worthy of this presentation.

The procedures described are strictly chemical laboratory methods. The information obtained by means of them is probably about as reliable as that gained by any other chemical methods and more illuminating than most others. The time and work required are very much less than are needed for the biological methods, such as those of Neubauer (6) or the various modifications of the Winogradsky (11) procedure. At the start, it is assumed that any satisfactory method must give results in general agreement with the indications given by plants growing in the same soil. It is known that what is adequate for one kind of plant may be quite insufficient for plants of another species, yet some plants must finally be relied upon to show whether a soil will produce more paying crops when phosphate fertilizers are used.

No review of the literature is given, and no discussion of published methods is offered. A considerable bibliography of the subject is given in a previous article by the writer (4). The present purpose is simply to make known, in order to leave to the judgment of others, the proposed methods. These methods were evolved from a study of those previously published, with some new invention.

Knowledge of three variables is necessary in order adequately to characterize the phosphate supplying power of a soil, the amount available to the plant at any one moment, the rate at which it will be restored to the original level when it is being withdrawn from the soil solution by any agency such as the growing plant, and the total amount which may become available during a considerable number of years. The latter may be very different from the total phosphate present in the soil. The content of some sort of acid extract has usually been relied upon to measure the amount of phosphate available at any one moment. The writer feels that most of the results thus obtained are of questionable value, likely to be overestimates. In the soil, carbonic acid is the chief agent for dissolving phosphates. Sometimes nitric acid may help. But the concentra-

tion of these acids in the soil is so small that their dissolving effect is little compared with that of the acids which have usually been employed in laboratory tests. Also, their concentration in the soil varies so greatly from time to time that it is too indefinite for a standard procedure. Since the soil water must be the chief agent for conveying soil phosphate to plants, it seems to be the logical solvent for extracting the available phosphate in a soil. Water free of CO_2 is difficult to maintain in that condition and is not like the soil solution, although it is advocated by Dirks and Scheffer (1) as the appropriate solvent for phosphate ion in nonalkaline soils. Ordinary distilled water containing some CO_2 is relatively constant in composition, is easily obtained, and is more like the soil solution than CO_2-free water; therefore it has been chosen as the most appropriate solvent for extracting soil phosphate. Better yet would be the study of actual soil solution. But it is difficult and expensive to extract it from any soil, and impossible to get from many soils. However, a 1:1 water extract is not difficult to obtain from any soil and in a majority of cases has about the same concentration of PO_4 as the actual soil solution. Table 2 shows that a 1:4 water extract will serve about as well as the 1:1 extract and, since it is easier to prepare, it is used to determine approximately the concentration of PO_4 in the soil solution.

PREPARATION OF WATER EXTRACT

The solution is prepared by shaking 50 gm. of soil with 200 cc. of ordinary distilled water in a closely stoppered bottle for an hour in an end-over-end shaker. The shaking should be very gentle. It has been found (5) that violent shaking makes a great difference in the amount of PO_4 dissolved from sandy soils. The length of time of shaking is arbitrarily set at 1 hour. Sometimes longer agitation will bring more PO_4 into solution, but 1 hour does very well for comparative purposes. After the shaking, the soil mixture is poured upon a phosphate-free filter paper in a Büchner funnel and the solution drawn through by suction. Since the first of the filtrate usually is turbid, it is returned to the filter till it comes through clear. Phosphate is determined in the filtrate by the molybdenum blue method as modified by Parker and Fudge (7). This gives a fair idea of the concentration of PO_4 in the soil solution immediately available to the plant, but it does not indicate the total easily available water-soluble PO_4 in the soil. For this purpose, a 1:100 water extract is made. This gives a solution about as dilute as is convenient for estimation of PO_4 by the molybdenum blue method, otherwise a still greater dilution would be preferable for soil having much easily soluble PO_4. The 1:100 water extract does not give the actual total water-soluble PO_4, but it does provide a figure which, for the purpose of comparison, is equivalent to the total or serves as well.

Preparation of the 1:100 water extract is similar to that of the 1:4 extra except for the method of filtration. In the latter, the soil itself is the real filtering medium, but in the 1:100 extract, there is not enough soil mass on the

filter to produce a clear filtrate by the usual method. A Büchner funnel with a 7-cm. filter such as Whatman 30 or S. and S. 589 is used with suction. To prevent creeping of the soil under the edge of the filter; suction must not be interrupted during filtration.

RECEIVER FOR CONTINUOUS FILTRATION

Accordingly a 2-bulb receiver is used. The two bulbs, one above the other, are connected by a stopcock between them, and also by a side tube provided with a 2-way stopcock connecting the upper portions of the two bulbs. The lower bulb has a stopcock for drawing off the filtrate. The Büchner funnel is connected with the upper bulb by a rubber stopper. In operation, both stopcocks between the bulbs are open at first and the filtrate collects in the lower bulb. When it begins to come through clear, the middle stopcock is closed and the other is turned to admit air to the lower bulb while the suction is held on the upper bulb so that filtration continues. The turbid liquid is drawn off from the lower bulb and returned to the filter or rejected. Now both stopcocks between the bulbs are opened again so that the filtrate collects in the lower bulb. In this manner of working, suction is continuous on the filter so that no soil can creep under the edge of the filter to make the filtrate turbid. If the soil is very coarse, it is sometimes helpful to add a little filter paper pulp to the soil suspension in order to obtain a clear filtrate.

RE-EXTRACTION OF THE SOIL

If it is desired to know something of the continued supplying power of the soil, the filter paper and soil from the first extraction are returned to the bottle with 200 cc. of water and the extraction is repeated as at first. A third extract may be prepared in the same manner. Further extracts are difficult to prepare on account of removal of electrolytes which aid filtration. Also, the added filter paper retains some PO_4 and makes the work cumbrous. The hardened filter papers from which the soil may be washed off, are not suitable because of their great tendency to retain phosphate. The three extracts obtained in this way serve very well to indicate the phosphate supplying power of the soil, both as to amount, and the rate at which it comes into solution. This method of repeated extraction is not proposed as a routine procedure. It is too laborious, but it will, in a short time, give considerable insight into the capacity of the soil to supply phosphate. Much the same information may be obtained with less labor though requiring a longer time by the percolation method.

THE PERCOLATION METHOD

In this procedure, a small portion of soil is percolated with water, or other solvent at a slow rate for 21 hours. The percolate is collected in seven portions successively so that each may be analyzed separately. After the apparatus is started, it requires very little attention till next day when the solutions are ready to be analyzed. The operation is entirely mechanical and automatic.

In order to obtain comparable results with different soils, the rate of percolation must be uniform. The same volume of reagent must pass through the same amount of soil in the same length of time. With the present apparatus, this is fairly well accomplished so long as the temperature does not vary much. Increase of temperature increases rate of flow so that hand adjustment is required to maintain constancy of flow. However this needs little attention. An apparatus intended to perform the same work was recently described (3). The present apparatus is much better than the earlier one.

THE PERCOLATION APPARATUS

On a shelf about 5 feet above the work bench stands a large bottle, fitted as a Mariotte bottle, of distilled water or other solvent. This siphons down to a 200-cc. bottle which maintains a nearly constant level supply for the siphons which, in turn supply the regulating tubes that control the rate of flow of the solvent to the percolating tubes. The regulating tubes are glass tubes about 8 mm. inside diameter, 30 cm. long, filled with clean fine acid-washed quartz sand which greatly retards the flow of the water though the tube. The tube is held at an angle of about 30° with the horizontal so that the lower end is a little below the top of the water in the constant level bottle. By suitable varying of the height of the regulating tube below the level of the water in the constant level bottle, the effective hydrostatic head on the regulating tube is changed as necessary to produce a constant rate of flow of about 40 drops a minute or 125 cc. in 3 hours. From the regulator, the water drops into an open tube which conveys it to the percolator tube.

The percolator is an ordinary filter tube such as is used for holding gooch crucibles. It is about 30 mm. inside diameter. In the bottom is a perforated porcelain plate on which rests the filtering medium. First is a layer about 4 mm. thick of paper pulp. This is held in place by a disk of brass gauze. After most of the water has been sucked out from the paper pulp by vacuum, 0.1 gm. of powdered talc suspended in 10 cc. of water is added and the water again drawn out. Then another 3-mm. layer of paper pulp is added, the water drawn out, and the whole well smoothed and packed down. A little acid-washed clean quartz sand is placed on top to aid in separating the filter from the soil in order to recover the paper pulp. Two and a half grams of the soil mixed with 5 gm. of the sand are added. On top is a wad of cotton 3 mm. thick pressed wet on top of the soil so that it will not be disturbed when the percolating water drops upon it. The layer of talc inclosed between two layers of paper pulp is the effective filtering medium, although but little of the soil passes through the upper layer of paper pulp to lodge on the talc. The whole constitutes an excellent filter which permits passage of the solvent at the desired rate and delivers an almost clear filtrate after the first 50 cc. of water have passed through. If the solvent is not pure water but contains some electrolyte to maintain flocculation of the soil, the filtrate is clear from the beginning. The percolator is closed at the top by a rubber stopper through which pass two

glass tubes. The small one, 3 mm. diameter, conducts in the solvent from the regulator tube located about 3 feet above. The other tube is about 8 mm. inside diameter and 80 cm. long, standing vertically. Its function is to allow escape of the air which is entrained along with the water, and to build up hydrostatic pressure on the percolator so that if the water does not pass through the soil and filter as fast as it comes from the regulator, the increased pressure caused by the column of water will soon be enough to maintain percolation at a constant rate. When the soil is sandy, no pressure is required. Very much clay in the soil slows filtration so that some pressure is needed to maintain the constant rate of flow.

From the percolator, the water drops into a small funnel which conducts it to the first collecting bottle. The collecting system is similar to that described in the previous paper (3) except that the bottles hold 125 cc. instead of 1,000 cc. The bottles are closed by 2-hole rubber stoppers. Through one hole passes a short open tube to permit escape of the air from the bottle. Through the other hole in the stopper passes the upright of a T tube. The horizontal arms of the "T" are connected by rubber tubing with the arm of the T tubes in the next bottle on each side so that the set of six bottles is consecutively filled by the liquid coming from the percolator. All of it drops into the first one till that is filled, then passes through the horizontal arms of the T tubes to the second bottle, and when that is filled to the third bottle, etc., till all six bottles are filled during the course of about 18 hours. Finally, the liquid from the last bottle drops into a large open jar, which is the seventh in the series. Very little of the liquid from the percolator mixes with that in the already filled collecting bottles. When the percolation is to be stopped, a pinch clamp is placed on the rubber tube which carries water from the constant level bottle to the regulating tube, thus stopping the flow but leaving the regulating tube full of water so that it will start again at once when the pinch clamp is removed.

After the extraction is finished, 100 cc. of the liquid is taken from each of the collecting bottles for determination of the phosphate by the molybdenum blue method. Another portion is used to determine the pH by indicators, and another portion is used to make an estimate of the calcium by turbidity when ammonium oxalate is added (2). Three percolators with their sets of collecting bottles are used by the writer. Analyzing the contents of the 21 bottles takes about 1½ hours. To clean out the percolators, to charge them with a new set of soils, and to set the apparatus in operation again requires 15 to 20 minutes. Thus it is possible to test a set of three soils every day in about 2 hours of the operator's time. The paper pulp used in the percolators is thrown into a large bottle of water to separate it from the soil and sand so that it may be recovered for further use.

In principle, this process is similar to the successive extraction method of von Wrangell (12) or the collodion bag diffusate method described by Pierre and Parker (8). It has the advantage over these of requiring no elaborate or expensive apparatus and much less of the operator's time and labor. In this

fairly simple manner, it is possible to measure the amount of easily soluble phosphate in the soil, the time rate at which it will be supplied by the soil, the level at which it will be supplied after the first easily soluble portion has been removed, and the pH of the solutions which indicate the buffer power of the soil, and give some idea of the amount of easily soluble calcium in the soil. The calcium thus dissolved seems to control somewhat the solubility of the phosphate (see table 4).

TOTAL EASILY SOLUBLE PHOSPHATE IN THE SOIL

In most soils, there is some phosphate not easily extracted by water but readily dissolved by dilute acids. Various workers have used a number of different acids of different concentrations. The writer has used 0.05 N HCl and 0.05 *N* H_2SO_4. The latter seems to have greater solvent power, therefore it has been preferred. For the extraction, 1 gm. of soil is placed in a Jena sintered glass filtering funnel, porosity 3, with 30 mm. filtering plate. A gooch filter with asbestos might be used if packed tight enough to make percolation slow. A 500-cc. flask with narrow neck is filled with 0.05 *N* H_2SO_4 and inverted with the mouth just above the soil and held by a clamp so that the liquid may run into the filter as fast as it percolates through. Several hours are required for the 500 cc. to pass through the soil and filter. After this, the collecting bottle is changed, the supply flask refilled, and another 500 cc. of extract is obtained. Next time, only 200 cc. of acid is placed in the supply flask and the percolate is received in another bottle. When the extraction is finished, the PO_4 in the three portions of extract is determined by the color method, as before stated. Usually, most of the phosphate is contained in the first 500 cc. of extract, with a little in the second and almost none in the third, showing that the soil has been exhausted of easily soluble PO_4. The extract is collected in three separate portions which are analyzed separately in order to determine something in regard to the ease of solubility and whether the extraction has been complete. One objection to this procedure is the long time required, which may be 2 or 3 days, for a single sample of soil. But in most cases, this is not important, since very little of the operator's time is needed. It is possible to draw the acid through the filter very much faster by the aid of suction, but a few experiments showed that the extraction was not so complete as when it proceeded by gravity over a longer time. Considerable time seems to be an essential feature of the process. Somewhat similar figures are obtained by the Truog method (9). But since the latter is an equilibrium process, it is not to be expected that the results obtained by the two methods should be alike. Probably the figures obtained by the Truog method will serve almost equally well to characterize the soil in most cases, with much less time and perhaps less labor. To make the matter clearer to those not familiar with it, a few details of the Truog method are given here.

TRUOG METHOD

Two grams of 20-mesh soil are shaken with 400 cc. of 0.002 *N* H_2SO_4 containing 0.3 per cent of ammonium sulfate for half an hour. The mixture is filtered and PO_4 determined in the clear filtrate by the molybdenum blue method as described by Truog and Meyer (10).

By the use of the methods described in the foregoing, non-alkaline soils are examined as to their content of readily available phosphate. The following outline of procedure is suggested as the shortest possible which will give the needed information. Probably about the same procedure may be used with peat soils. Alkaline or calcareous soils must be tested by different reagents and perhaps by different procedures.

ESTIMATING THE AMOUNT OF PLANT AVAILABLE PHOSPHATE IN A SOIL

Test for carbonate by adding HCl, and determine pH by a suitable indicator, cresol red or phenolphthalein. If the soil effervesces or has a pH over 8, it is to be considered as alkaline and must be tested for PO_4 by other special methods. If the soil is not alkaline make the Truog test. If the PO_4 is very high or very low, no other test is needed to characterize the soil. If the Truog test indicates a medium amount of PO_4, other tests are needed.

Make water extracts 1/1 or 1/4 and 1/100. If the concentration of PO_4 in both is above 0.2 p.p.m. and above 500 in the Truog test, no other test is needed, but if the Truog test is 300 or less, it may be well to make the test by percolation with water, and with 0.05 *N* H_2SO_4.

INTERPRETATION OF THE RESULTS

In most sandy soils, and in some loams and clays, the concentration of PO_4 is higher in the 1/1 or 1/4 than in the 1/100 water extract indicating some relatively easily water-soluble PO_4. Successive 1/100 water extracts or percolation extracts of such a soil are likely to show rapidly decreasing concentrations of PO_4 so that the soil will be soon depleted of available PO_4 by heavy cropping, and may, within a few years, need phosphate fertilizer. But if there is little difference between the concentration of PO_4 in the 1/4 and the 1/100 water extracts, the soil contains very little easily water-soluble PO_4. If the concentration is below 0.2 p.p.m., it is probable that it will pay to use a phosphate fertilizer for such crops as potatoes or tomatoes which need plenty of available phosphate. If it is below 0.1 p.p.m. and the Truog test gives less than 300 p.p.m. PO_4, the soil is rated very poor in available phosphate. Probably the soil will be unable to supply available phosphate fast enough to grow good crops of barley or alfalfa. If it is over 0.2 p.p.m. in the 1/100 water extract and over 600 by the Truog test, the soil is not likely to need phosphate for some years. A fine textured soil is likely to have a more lasting supply of phosphate than a coarse soil which gives the same amount in any of the tests.

Soils which have a high level at first, such as 0.5 to 1+ p.p.m. in 1/100 water

TABLE 1

PO_4 extracted by various methods

SOIL NUMBER	TEXTURE	$CaCO_3$	pH	FUSION	0.2 *N* HNO_3	PERCOLATE WITH 0.05 *N* H_2SO_4	TRUOG EQUILIBRIUM 0.002 *N* H_2SO_4	WATER		
								Percolation	Equilibrium	
									1:1 or 1:4	1:100
		per cent		*p.p.m.**	*p.p.m.**	*p.p.m.**	*p.p.m.**	*p.p.m.**	*p.p.m.†*	*p.p.m.†*
1c	Silty clay loam	0	6.7	2,000	400	1,104	620	60	0.20	0.18
30	Sandy loam	0	6.9	1,600	1,120	1,250	440	68	5.00	0.40
35	Sandy loam	0	5.4	2,400	80	527	20	6	0.04	0.03
36	Sandy loam	0	6.8	2,500	220	802	330	42	0.12	0.14
37	Sandy loam	1.0	8.2	2,400	250	870	400	39	0.58	0.18
38	Clay loam	0	7.2	2,500	80	876	248	60	0.18	0.21
40	Loam	0	6.3	3,300	1,080	2,042	800	340	5.00	0.88
53	Fine sand	0	7.1	800	500	680	88	37	1.32	0.27
59	Clay loam	0	6.0	2,000	2	134	4	0	0	0
64	Loam	0	6.9	1,700	270	979	160	20	0.10	0.08
65	Silty clay loam	0	7.1	2,800	.....	1,529	800	154	2.00	0.72
68	Sandy loam	0	7.5	1,400	.....	1,460	200	35	0.24	0.10
78	Sandy loam	0	4.8	450	.....	118	20	13	0.20	0.06
80	Loam	0.4	8.3	1,150	500	722	260	20	0.16	0.06
A	Peat	.....	....	.....	.....	1,041	100	44	0.04	0.04
B	Peat	.....	....	.....	.....	662	88	66	0.26	0.28
C	Peat, same as B plus superphosphate	.....	....	.....	.....	1,165	288	200	0.48	0.68

Rich in available phosphate: 1c, 30, 40, 65.

Medium in available phosphate: 36, 37, 38, 53, 68.

Poor in available phosphate: 35, 59, 64, 78, 80.

36, 37, 38 are too low in water soluble.

53 has too little acid soluble, though it is high in water soluble.

80 has plenty of PO_4, but is too alkaline.

* In soil. † In solution.

Comments: Some figures indicating the general character of the soils and their response to the phosphate tests are presented. In some cases, the total PO_4 has no relation to availability, as in 35, 36, 37, 59, 64, and 80. The PO_4 dissolved by the comparatively strong acid, 0.2 *N* HNO_3, in some cases gives a correct estimate of the availability. But in the cases of 38, 53, 64, and 80, its indication is misleading. Of these, 38 is the best in respect to ability to supply growing plants with adequate PO_4. In the greenhouse, 38 has demonstrated its superiority in growing nine consecutive crops of barley and tomatoes. Soil 64 contains more easily acid-soluble PO_4 than 38, but it cannot give a high enough concentration in the water extracts. Soil 53 has relatively high easily water-soluble PO_4 but the total easily available PO_4 (Truog) is much too low. It is quickly exhausted by cropping. Soil 80 is too alkaline to permit easy solution of its good supply of easily acid-soluble PO_4.

Both dilute acid-soluble (Truog), and water-soluble phosphate are so high in soils 1c, 30, 40, and 65 that these are at once classed as rich soils, whereas by the same tests, 35, 59, and 78 are very poor. The figures indicate that 37 is better than 38, yet all pot culture work shows that 38 is one of the best in the whole lot, whereas 37 is in the medium to poor class. This shows that the chemical tests are not always capable of giving the correct rating to a soil. In this case, however, 37 is so alkaline, pH 8.2, that its phosphate is relatively poorly available, the same as in 80.

extract, but which level rapidly falls off with successive extracts, are likely to produce large crops at first, if other nutrients are adequate, but soon fall off in productivity.

Total PO_4 or strong acid-soluble PO_4 is frequently no guide to the amount of available phosphate in the soil, unless, when very low, it shows an absolute deficiency. Dilute acid-soluble, Truog or 0.05 *N* H_2SO_4 percolate-soluble phosphate, probably measures the total easily available PO_4, or all that plants are likely to be able to obtain in many years.

To obtain a better idea of the power of the soil to maintain an adequate supply of phosphate for heavy cropping, the test by percolating with water is

TABLE 2

PO_4 extracted from soils by water in various ratios of soil to water

SOIL		PO_4 IN THE SOLUTION AT RATIOS OF SOIL TO WATER				
		1/1	1/5	1/20	1/50	1/100
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
1c	*A. Loams*	0.20	0.36	0.22	0.22	0.18
38		0.18	0.20	0.22	0.22	....
64		0.10	0.08	0.08	0.08	0.10
68		0.24	0.20	0.10	0.10	....
80		0.16	0.16	0.12	0.10	0.06
65		2.00	2.40	1.74	1.14	0.72
30	*B. Sandy soils*	8.00	2.90	1.16	0.58	0.30
37		0.58	0.50	0.40	0.22	....
53		1.70	1.00	0.50	0.31	....
35		0.04	0.03	0.04	0.05	0.03
68		0.24	0.20	0.10	0.10	0.07

A soils have little easily water-soluble PO_4.

B soils have considerable easily water-soluble PO_4.

Usually this easily water-soluble PO_4 is rapidly diminished by intensive cropping, while the less easily soluble PO_4 in the *A* soils may supply PO_4 rapidly enough to produce good crops many years if it is high enough at the start.

This table is presented in order to show that in many cases, the ratio of soil to water makes little difference in the concentration of PO_4 in the extract.

most illuminating. Three successive extracts at 1/100 ratio give the same kind of information in much shorter time but requiring much more labor. A graph made by plotting the results of the percolation test shows at a glance the character of the soil with regard to phosphate.

The buffer power of the soil and the rate at which it reacts with a neutralizing agent are very important in laboratory tests where time is an important factor. In the field, the time rate may be unimportant, but in the laboratory if too little time is allowed for the test, the buffer power may be much underestimated.

Tables 1 to 4 with appended notes are self-explanatory and are included to give the reader an idea of the magnitudes involved in this sort of soil tests.

TABLE 3

PO_4 extracted from soils by percolation with water compared with PO_4 in successive equilibrium extracts

p.p.m. PO_4 in soil

SOIL	METHOD*	EXTRACT NUMBERS							TOTAL
		1	2	3	4	5	6	7	
1c	P.	0.16	0.09	0.06	0.06	0.06	0.06	0.06	0.55
	E.	0.20	0.15	0.22	....	....	....	....	0.57
30	P.	0.31	0.10	0.09	0.08	0.07	0.07	0.06	0.78
	E.	0.54	0.34	0.08	....	....	....	....	0.96
35	P.	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.10
	E.	0.06	0.02	0.02	....	....	....	....	0.10
36	P.	0.10	0.08	0.06	0.05	0.04	0.04	0.03	0.40
	E.	0.14	0.12	0.10	....	..	....	....	0.36
37	P.	0.13	0.06	0.05	0.05	0.04	0.04	0.03	0.40
	E.	0.17	0.10	0.03	....	....	....	....	0.30
38	P.	0.15	0.13	0.08	0.07	0.06	0.05	0.05	0.59
	E.	0.20	0.08	0.08	....	....	....	....	0.36
40	P.	1.25	0.50	0.33	0.20	0.15	0.11	0.22	2.62
	E.	0.88	1.00	1.00	....	....	....	....	2.88
53	P.	0.15	0.06	0.05	0.04	0.03	0.03	0.02	0.38
	E.	0.27	0.07	0.06	....	....	....	....	0.40
64	P.	0.07	0.06	0.03	0.03	0.02	0.02	0.01	0.24
	E.	0.08	0.04	0.06	....	....	....	....	0.18
65	P.	0.50	0.28	0.28	0.15	0.11	0.11	0.10	1.53
	E.	0.32	0.44	1.00	....	....	....	....	1.76
68	P.	0.07	0.06	0.06	0.05	0.05	0.04	0.03	0.36
	E.	0.14	0.08	0.05	....	....	....	....	0.27
78	P.	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.15
	E.	0.06	0.04	0.04	....	....	....	....	0.14
80	P.	0.01	0.04	0.05	0.05	0.05	0.06	0.07	0.33
	E.	0.06	0.04	0.02	....	....	....	....	0.12

* P. = percolation; E. = equilibrium.

Comments: Table 3 permits a comparison of the amounts of PO_4 extracted by continuous percolation and by successive equilibrium extracts. It also gives an idea of the rate at which the different soils give their PO_4 up to a water extract. The equilibrium extracts have higher concentration than the percolation extracts because all the PO_4 that can dissolve in the water is entirely removed by filtration at each extraction, which is quite different from the percolation process in which there is no such complete separation between successive percolates. However, it is evident that the quantities found by the two procedures run parallel, thus giving a similar character to the soil.

The figures show how rapidly the easily soluble PO_4 is removed from rich soil such as 40 and 65, how the high buffer alkalinity of 80 retards solution of PO_4, how the poor character of 35 and 78 is indicated by the low concentrations in the extracts, and why soil 38 is so much better than 64, although the latter has more PO_4 easily soluble in dilute acid, 0.2 *N* HNO_3 (table 1). Soil 38 has a much higher rate of solution in water, and a higher total PO_4 which enables it to maintain for a long time a high enough concentration in the soil solution to produce good crops.

TABLE 4

Tentative standards for availability of soil phosphate as estimated by various methods

KIND OF SOIL	PO_4 IN SOIL		PO_4 IN SOLUTION—EQUILIBRIUM WATER EXTRACTS	
	Truog acid soluble	Water by percolation	1:1 or 1:4	1:100
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
Rich silty clay loam	Over 500	Over 60	Over 0.25	Over 0.20
Medium loam	200–500	30–60	0.15–0.20	0.15–0.20
Poor loam	Below 200	Below 30	Below 0.10	Below 0.10
Rich sandy loam	Over 600	Over 80	Over 5.00	Over 0.40
Medium sandy loam	300–600	35–70	0.25–1.00	Over 0.20
Poor sandy loam	Below 300	Below 20	Below 0.25	Below 0.15

Analysis of more soils of well-known field behavior in respect to phosphate supplying power will be necessary to establish the limits more definitely.

Comments: Table 4 sets forth tentative standards to be used in interpreting an analysis of a soil by the proposed methods. Soils in the class "rich" are not likely to be able to produce much better crops from applications of phosphate fertilizers. The "poor" soils are likely to need phosphate in order to produce good crops. The medium soils may give good yields of some crops for several years without receiving any phosphate fertilizer, but for good yields of plants requiring much PO_4, it may pay to use fertilizer at first. Much more work must be done with soils of known field behavior before it will be possible to interpret the results of an analysis of an unknown soil with any great degree of precision.

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COMPARISONS IN THE DISTRIBUTION OF NEMATODE GALLS ON THE ROOTS OF PINEAPPLE VARIETIES ATTACKED BY THE NEMATODE HETERODERA RADICICOLA (GREEF) MÜLLER[1]

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Pineapple plants are quite generally infected by the root knot nematode in the Hawaiian Islands except for certain areas to which it has not yet been distributed. An analysis of the damage to the roots of several varieties of young plants has been made recently by Collins and Hagan (2). Some additional data, not given in their report but obtained from the same experiments, may have considerable economic and theoretical significance quite apart from a comparative study of the injury suffered directly by the crop attacked. This information consists of comparisons between varieties of pineapples in the number of galls produced, their distribution on the roots, their relation to reduction in root length, and their influence upon the future nematode population of the soil. The following information is briefly presented in order to make these comparisons: Differences between varieties in the number of non-terminal galls per plant; Differences between varieties in the number of terminal galls per plant; Differences between varieties in the total number of galls per plant; Differences between varieties in the number of galls per root; Differences between varieties in the number of galls per foot of root length.

Nematode infection also is present in the fine fibrous roots, but no tabulations of data on this subject have been included. Some pineapple varieties have few such roots whereas others have dense masses of them. Observations of this condition have shown no reliable method of evaluating infection in the fibrous roots which could be used in comparative studies. The galls are very small. Many are lost in freeing the roots from soil, the greatest absolute loss occurring on plants with the largest numbers of such roots. Likewise, it has been impossible to make any estimate of the abundance of nematodes within the older parts of the roots, where they form no galls. The labor necessary, the time consumed, and the resultant damage to the plant through drying and breaking of fibrous roots make these analyses impracticable.

This paper includes comparative studies on the following varieties of pineapples: Cayenne, Hilo, Lot 520 (F_1 hybrid of Cayenne x Wild Brazil), Natal,

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Pernambuco, Ruby, Taboga, and Wild Kailua. Only the first two are grown commercially in the Hawaiian Islands, but all of them are used for investigational work at the Pineapple Experiment Station. Sixteen plants of each variety were grown, except that there were 12 Cayenne and 32 Hilo plants in the test. Each container, of 3 gallons soil capacity, held two plants. A uniform, fairly heavy inoculation of 50 nematode egg masses was placed in each container shortly after root growth started. The plants were permitted to grow approximately 8 months before being removed from the soil for these observations. Further information regarding the routine of the experiment may be obtained from the more detailed report by Collins and Hagan (2).

The galls found in this analysis have been divided into two groups according to their location on the roots. Those situated apically are classed as terminal galls, whereas others, scattered along the roots and not at the root tips, are called "non-terminal galls." In the tables presented, the figures given represent arithmetical differences between varieties in the number of galls possessed by them in the comparisons that are made. The probable errors of the differences also have been entered that the reader may judge how significant the figures may be or how closely such differences approach significance. Regardless of significance, arrows point to the variety with the greater number of galls in each comparison, and the letter *s* has been added to significant differences in order that they may be more easily detected.[2]

DISTRIBUTION OF GALLS

Differences between varieties in the number of non-terminal galls per plant are shown in table 1. Ruby has fewer than Cayenne, Hilo, Lot 520, or Natal; Taboga fewer than Hilo, Lot 520, or Natal; Wild Kailua has a smaller number than Hilo or Natal. The remaining differences are not statistically significant, yet a definite trend manifested in two of the varieties, Natal and Ruby, should not pass unnoticed, as it is entirely possible that these differences might assume significance with larger populations of plants. In all comparisons, the arrows are directed away from Ruby, indicating that this variety has the fewest non-terminal galls. Natal, on the contrary, probably has the greatest number, as all of the arrows point toward this variety.

Table 2 gives the differences between varieties in the number of terminal galls per plant. There are 22 significant differences in the 28 comparisons. Taboga has the fewest galls. Cayenne and Hilo have an equal number, which

[2] Since this consideration of the purely nematological phases of pineapple infection originates from data gathered in tests already reported by Collins and Hagan (2) on the nematology-genetics aspects of the work, the writer is indebted to the same sources for help in recording the original data. Further, through the courtesy of the *Journal of Heredity*, some information appearing in the afore-mentioned article, important here for the purposes of reference or comparison, has freely been drawn upon, especially in the preparation of table 6. Some slight discrepancies appear between these figures and those given in the original paper, since the present figures have been carried to one more decimal point.

greatly exceeds the number of terminal galls possessed by any of the other varieties. Since none of the varieties is immune to attack, we would expect to find that those with the greatest number of main roots would also have more terminal galls per plant; and, upon inspection, such is found to be the case.

A comparison of the figures in table 1 with those in table 2 shows that in every instance, where an actual difference exists between varieties in the number of

TABLE 1

Differences between varieties in number of non-terminal galls per plant

Arrow indicates variety with greater number; *s* indicates a significant comparison.

VARIETY	CAYENNE	HILO	LOT 520	NATAL	PERNAMBUCO	RUBY	TABOGA
Hilo	1.78 ±2.40 ←						
Lot 520	0.41 ±2.41 ↑	2.19 ±1.90 ↑					
Natal	2.59 ±2.49 ←	0.81 ±2.00 ←	3.00 ±2.02 ←				
Pernambuco	2.78 ±3.24 ↑	4.56 ±2.87 ↑	2.37 ±2.89 ↑	5.37 ±2.95 ↑			
Ruby	10.16 ±2.03 *s* ↑	11.94 ±1.38 *s* ↑	9.75 ±1.41 *s* ↑	12.75 ±1.54 *s* ↑	7.38 ±2.58 ↑		
Taboga	7.10 ±2.16 ↑	8.88 ±1.57 *s* ↑	6.69 ±1.60 *s* ↑	9.69 ±1.71 *s* ↑	4.32 ±2.68 ↑	3.06 ±0.92 ←	
Wild Kailua	6.73 ±2.20 ↑	8.51 ±1.62 *s* ↑	6.32 ±1.64 ↑	9.32 ±1.75 *s* ↑	3.95 ±2.71 ↑	3.43 ±0.99 ←	0.37 ±1.24 ←

non-terminal galls, there is a correspondingly significant variation in the number of terminal galls, except in the case of the Lot 520-Ruby comparison. It might be well, also, to point out at this time that ratios of terminal galls to total galls present on the roots of each variety, expressed in percentages of total galls, are as follows: Ruby, 77 per cent; Cayenne, 71 per cent; Hilo, 68 per cent; Pernambuco, 67 per cent; Wild Kailua, 59 per cent; Taboga, 57 per cent; Natal, 55 per cent; Lot 520, 54 per cent. From these figures it will be

seen that table 2 takes into consideration the majority of the galls in the roots of the plants.

Table 3 gives the differences between varieties in the total number of galls per plant. The 28 comparisons show significant differences in 20 cases and 19 of these are duplicates of differences found in table 2. Not only are the differences significant in both cases, but their arrows agree in direction as well.

TABLE 2

Differences between varieties in number of terminal galls per plant

Arrow indicates variety with greater number; *s* indicates a significant comparison.

VARIETY	CAYENNE	HILO	LOT 520	NATAL	PERNAMBUCO	RUBY	TABOGA
Hilo	2.13 ±2.70 ↑						
Lot 520	20.25 ±2.26 *s* ↑	18.12 ±1.59 *s* ↑					
Natal	15.28 ±2.44 *s* ↑	13.15 ±1.83 *s* ↑	4.97 ±1.07 *s* ←				
Pernambuco	12.50 ±2.53 *s* ↑	10.37 ±1.96 *s* ↑	7.75 ±1.30 *s* ←	2.78 ±1.58 ←			
Ruby	21.69 ±2.30 *s* ↑	19.56 ±1.65 *s* ↑	1.44 ±0.72 ↑	6.41 ±1.16 *s* ↑	9.19 ±1.36 *s* ↑		
Taboga	26.75 ±2.32 *s* ↑	24.62 ±1.67 *s* ↑	6.50 ±0.78 *s* ↑	11.47 ±1.20 *s* ↑	14.25 ±1.39 *s* ↑	5.06 ±0.90 *s* ↑	
Wild Kailua	25.68 ±3.02 *s* ↑	23.55 ±2.56 *s* ↑	5.43 ±2.09 ↑	10.40 ±2.28 *s* ↑	13.18 ±2.38 *s* ↑	3.99 ±2.13 ↑	1.07 ±2.15 ←

One significant difference given here that does not appear significant in table 2, is the Lot 520-Ruby comparison. This comparison owes its significance in table 3 to the great difference between the two varieties in number of non-terminal galls, table 1. On the other hand, table 3 lacks the statistically significant differences which exist in table 2 for Lot 520-Natal, Lot 520-Pernambuco, and Ruby-Taboga comparisons. Even when significant differences are lacking in tables 2 and 3, it will be observed that the arrows agree in direction, except for the Natal-Pernambuco comparisons.

In table 4 are found the differences between varieties in the number of galls

per root. Cayenne, Hilo, and Lot 520, have almost equal infections in this classification. Natal has more galls per root than Hilo, Lot 520, Ruby, or Wild Kailua. Ruby has significantly fewer than Lot 520, Natal, Pernambuco, or Taboga, and in every comparison the arrow points away from this variety.

One sees, in table 5, only four significant differences between varieties in the number of galls per unit of root length. Cayenne has more galls than Lot 520.

TABLE 3

Differences between varieties in total number of galls per plant

Arrow indicates variety with greater number; *s* indicates a significant comparison.

VARIETY	CAYENNE	HILO	LOT 520	NATAL	PERNAMBUCO	RUBY	TABOGA
Hilo	0.35 ±3.67 ↑						
Lot 520	20.54 ±3.61 *s* ↑	20.19 ±3.44 *s* ↑					
Natal	13.54 ±3.36 *s* ↑	13.19 ±3.16 *s* ↑	7.00 ±3.10 ←				
Pernambuco	14.72 ±3.51 *s* ↑	14.37 ±3.33 *s* ↑	5.82 ±3.27 ←	1.18 ±2.98 ↑			
Ruby	31.98 ±2.84 *s* ↑	31.63 ±2.61 *s* ↑	11.44 ±2.53 *s* ↑	18.44 ±2.15 *s* ↑	17.26 ±2.38 *s* ↑		
Taboga	33.75 ±2.97 *s* ↑	33.50 ±2.75 *s* ↑	13.31 ±2.68 *s* ↑	20.31 ±2.32 *s* ↑	19.13 ±2.54 *s* ↑	1.87 ±1.48 ↑	
Wild Kailua	27.79 ±3.22 *s* ↑	27.44 ±3.02 *s* ↑	7.25 ±2.96 ↑	14.25 ±2.64 *s* ↑	13.07 ±2.83 *s* ↑	4.19 ±1.93 ↑	6.06 ±2.13 ←

Taboga has more than Lot 520, Natal, and Wild Kailua. Although not statistically significant, is it interesting to note that all arrows, indicating arithmetical differences, point toward Cayenne, and all are directed away from Wild Kailua.

DISCUSSION AND APPLICATION OF DATA

Uniformity of infection

Table 5 is especially interesting and significant in this paper since it reveals so few statistically important differences between varieties in the number of

galls per unit of root length. Regardless of size, vigor, or kind of plant, the number and length of roots, or other varietal characteristics of growth, we find that nematode attack is remarkably uniform in all varieties, when the relative root lengths are taken into consideration together with the number of galls formed on them. Even two of the four cases of significant differences found in the table are only barely significant. That is, the difference between Cayenne

TABLE 4

Differences between varieties in number of galls per root

Arrow indicates variety with greater number; *s* indicates a significant comparison.

VARIETY	CAYENNE	HILO	LOT 520	NATAL	PERNAMBUCO	RUBY	TABOGA
Hilo	0.080 ±0.075 ↑						
Lot 520	0.013 ±0.085 ←	0.093 ±0.054 ←					
Natal	0.335 ±0.086 ←	0.415 ±0.055 *s* ←	0.322 ±0.068 *s* ←				
Pernambuco	0.145 ±0.091 ←	0.225 ±0.063 ←	0.132 ±0.074 ←	0.190 ±0.075 ↑			
Ruby	0.214 ±0.076 ↑	0.134 ±0.040 ↑	0.227 ±0.056 *s* ↑	0.549 ±0.057 *s* ↑	0.359 ±0.064 *s* ↑		
Taboga	0.133 ±0.102 ←	0.213 ±0.078 ←	0.120 ±0.088 ←	0.202 ±0.088 ↑	0.012 ±0.093 ↑	0.347 ±0.080 *s* ←	
Wild Kailua	0.052 ±0.087 ↑	0.028 ±0.058 ←	0.065 ±0.070 ↑	0.387 ±0.071 *s* ↑	0.197 ±0.077 ↑	0.162 0.060 ←	0.185 ±0.090 ←

and Lot 520 has a probable error which bears a ratio to the difference (D/E) of 4.06; the ratio between difference and probable error of the Taboga-Wild Kailua comparison is almost equally small (D/E equals 4.18). The Lot 520-Taboga value of D/E is 5.38 and Natal-Taboga D/E is 5.23.

The significant differences of Taboga when compared with Lot 520, Natal, and Wild Kailua, may express a true varietal difference between this variety and the others in the matter of relative susceptibility to attack, but with the

small number of plants used in the test the relatively greater apparent susceptibility of Taboga cannot be established as a fact. However, it may be pointed out that, except for the Cayenne-Taboga comparison, all arrows point toward this variety in table 5. Similarly, two other varieties, Cayenne and Wild Kailua, have already been mentioned because their differences, when compared with the others, seem to be constantly in favor of one and unfavorable to

TABLE 5

Differences between varieties in numbers of galls per foot of root length

Arrow indicates variety with greater number; *s* indicates a significant comparison.

VARIETY	CAYENNE	HILO	LOT 520	NATAL	PERNAMBUCO	RUBY	TABOGA
Hilo	1.07 ±0.52 ↑						
Lot 520	1.87 ±0.46 *s* ↑	0.80 ±0.32 ↑					
Natal	1.77 ±0.45 ↑	0.70 ±0.31 ↑	0.10 ±0.18 ←				
Pernambuco	1.38 ±0.47 ↑	0.31 ±0.34 ↑	0.49 ±0.24 ←	0.39 ±0.21 ←			
Ruby	1.15 ±0.46 ↑	0.08 ±0.33 ↑	0.72 ±0.21 ←	0.62 ±0.19 ←	0.23 ±0.24 ←		
Taboga	0.20 ±0.52 ↑	0.87 ±0.40 ←	1.67 ±0.31 *s* ←	1.57 ±0.30 *s* ←	1.18 ±0.33 ←	0.95 ±0.32 ←	
Wild Kailua	2.04 ±0.55 ↑	0.97 ±0.44 ↑	0.17 ±0.37 ↑	0.27 ±0.35 ↑	0.66 ±0.38 ↑	0.89 ±0.37 ↑	1.84 ±0.44 *s* ↑

the other in the number of galls per foot of root length. Aside from these possible exceptions, we must conclude that table 5, in general, shows equal infection of the varieties of pineapple plants tested, when varietal differences in root length are considered.

The variation in the number of terminal and non-terminal galls possessed by the different varieties of pineapples must be accounted for in other ways than by assuming a differential in susceptibility. The average number of non-

TABLE 6

Pineapple varieties listed to show increasing values in average numbers of non-terminal galls, terminal galls and roots, and average length of roots

A correlation is evident in the listings in columns 1 and 2 and also in columns 3 and 4.

NON-TERMINAL GALLS		ROOT LENGTHS IN FEET		TERMINAL GALLS		ROOT NUMBER	
Variety	Average number	Variety	Average length	Variety	Average number	Variety	Average number
Ruby	4.25 ±0.37	Taboga	4.95 ±0.39	Taboga	10.00 ±0.67	Taboga	10.81 ±0.53
Taboga	7.31 ±0.84	Ruby	6.96 ±0.32	Wild Kailua	11.07 ±2.05	Ruby	16.93 ±0.57
Wild Kailua	7.68 ±0.92	Wild Kailua	12.20 ±0.80	Ruby	15.06 ±0.60	Wild Kailua	17.62 ±1.22
Pernambuco	11.63 ±2.55	Pernambuco	14.71 ±0.78	Lot 520	16.50 ±0.42	Natal	25.00 ±0.22
Lot 520	14.00 ±1.36	Lot 520	14.84 ±0.94	Natal	21.47 ±1.00	Lot 520	26.90 ±1.89
Cayenne	14.41 ±2.00	Cayenne	15.51 ±1.29	Pernambuco	24.25 ±1.22	Pernambuco	28.38 ±1.25
Hilo	16.19 ±1.33	Natal	17.42 ±0.77	Hilo	34.62 ±1.54	Cayenne	38.66 ±1.76
Natal	17.00 ±1.49	Hilo	20.21 ±0.82	Cayenne	36.75 ±2.23	Hilo	42.44 ±1.25

terminal galls in each variety seems to vary with the average length of roots. Varieties with shorter root systems have fewer of them while those with longer root systems have more. Terminal galls, on the other hand, vary directly with the average number of main roots grown in each variety of pineapple. Only exceptionally will more than one terminal gall occur at the tip of a root, although this condition can be found when a lateral root pushes out beside the first terminal gall and, in turn, is attacked by nematodes. Some root tips, naturally, escape infection up to the time the tests are closed, so a perfect correlation between number of roots and number of terminal galls is not expected. It follows, however, that varieties with a greater number of roots may be found to possess a proportionally higher number of terminal galls. It is physically impossible for a variety with few roots to have as many terminal galls as one with many roots.

Comparisons of the two classes of galls with average root length and average number of roots may be made by glancing at table 6. As one reads down each column, the values increase in amount until the last plant mentioned will be observed to have the highest value in that column. Comparing the order in which the plants are placed under "Non-terminal Galls" with the list in column 2, one can readily see that the arrangement of the plants in the two columns is almost identical. Similarly, columns 3 and 4 may be compared with like results. Had these two sets of comparisons been shown in graphs, with galls on the ordinates and roots on the abscissas, the varieties would have been distributed in fair proximity to a diagonal line bisecting the angle formed at the origin of these axes. Thus a positive correlation is shown to exist between varieties in the number of non-terminal galls and root length, and a similar relationship appears when terminal galls and root numbers are compared.

The small number of plants representing each variety prohibits the use of Product-Moment correlation tables to determine the precise values of the aforementioned relationships. Nevertheless, the number of non-terminal galls, terminal galls, number of roots, and root lengths are all known to vary significantly for the several varieties, at least in many of the comparisons (table 6). Rank-Difference correlation may, perhaps, be used to express the presence of such relationships without necessarily indicating their extent. By this method, the correlation between number of non-terminal galls and length of roots, for the eight varieties is 0.95 ± 0.024. The correlation is 0.92 ± 0.038 when the number of terminal galls is associated with the number of roots possessed by each variety.

Varietal tolerance and root length reduction

We have concluded that, with a uniform inoculation, the different pineapple varieties have shown remarkable uniformity in the number of galls formed on each linear foot of root length grown by each variety. Table 6, however, makes it quite evident that certain varieties actually possessed many more galls than others at the end of 6 months' exposure to infection. Also, the varieties differ,

not only in number of roots, but in length of roots as well, according to Collins and Hagan (2). From this information, it might be determined whether nematodes cause a reduction in root length due solely to their abundance on the roots, or whether the different varieties of pineapples react differently to nematode attack and thus suffer in length of roots. If nematodes are entirely responsible for root length reduction then it might be expected that those varieties with the greatest number, or proportionally greatest number of galls, i.e. largest numbers of parasites, would suffer most. Varieties with smaller populations of the parasite should be less affected, and their root systems be less severely damaged. On the other hand, if plant response is the determining factor, then we would expect more resistant varieties to show less root loss than others, even when their roots bear large populations of nematodes. In other words, is degree of infection also a measure of damage when different varieties of pineapples are compared? Goodey (5) has shown that, within limits, an index of susceptibility could be determined and associated with a measure of plant injury in legumes attacked by *Tylenchus dipsaci*. That is, among his varieties, he could find some with light infections and with moderate damage to the plants. Another lot with heavier infections suffered more damage; whereas a third group, severely infected, showed greatest injury.

Perhaps one of the quickest methods of determining whether the nematode parasite or relative varietal tolerance of the host plant is the major factor in root length reduction is to employ the Rank-Difference correlation formula:

$$rho = 1 - \frac{6\,\Sigma D^2}{N\,(N^2 - 1)}$$

The probable error of each correlation may be ascertained by the following formula:

$$\text{P.E.}_r = \frac{.7063\,(1 - r^2)}{\sqrt{N}}$$

Both formulae are taken from Garrett (3). Obviously, infested roots alone cannot be considered, for it is entirely possible that uninfested roots might grow longer in order to compensate for the abnormal shortening of the others. Therefore, the correlations have been computed on the basis of average reduction in length per root for each variety.

When Rank-Difference correlation is ascertained for average reduction in length per root and number of galls per root, the value or $rho = 0.239 \pm 0.020$. The correlation in average number of terminal galls per root is 0.358 ± 0.045. Correlation based on the average number of non-terminal galls per root equals 0.143 ± 0.017. Since $N = 8$ the probable errors are quite apt to be larger than those given by the formula used. There is no correlation for the average number of galls per foot of root length as the answer is 0.048 ± 0.024; and a negative correlation appears to exist for total galls as $rho = -0.71 \pm 0.124$.

Apparently there is very little, if any, evidence in these data that the number of galls, terminal galls, galls per foot of root length, or galls per root, found in any variety, and associated with a definite amount of root length reduction in that variety, can be used to predict what will happen to any of the other varieties when attacked by nematodes. They have not responded alike, or the above correlations would be high, therefore varietal response must be intrinsic and different in value for the different varieties.

Nematode populations

Some consideration may now be given to the question of nematode populations. It is not yet known whether the same number of nematodes will produce galls of equal sizes on the different varieties of pineapples. No variety seemed to have a preponderance of galls of any one size in its roots in this study; therefore, the nematode population in the different varieties at the end of the experiment was assumed to vary, in general, according to the average number of galls present in each variety.

Of the factors favoring a rapid increase in the nematode population—Chapman's (1) biotic potential—only three are of special interest here. The first of these is the matter of fecundity. The egg masses used for the original soil inoculations contained, perhaps, about 500 eggs in each ootheca. Egg masses subsequently deposited within the pineapple root galls may have averaged the same, or approached this figure. Whatever the actual number may have been, one fact remains outstanding; that is, the rate of increase is very high. Actual field conditions seem to permit the same rate of multiplication.

Field observations have shown that several generations occur annually. Godfrey and Oliveira (4) have determined the minimum elapsed time for the life cycle in pineapple roots to be approximately 35 days. The plants used in this test were exposed to infection for 6 months which might permit of four or five generations forming the galls tabulated here. Under field conditions, the pineapple cycle usually covers 30 months and the number of generations is thereby considerably increased.

Temperature, too, has a very decided effect upon the length of the life cycle, and the number of nematode generations possible within a given period of time will be determined by this factor, if other conditions are uniform. Therefore, although this species of nematode continues its active development throughout the year in the Hawaiian Islands, population increase is much more rapid during the summer months.

The figures in table 3 may be interpreted from the viewpoint of increase in the nematode population. Cayenne and Hilo varieties have the same number of galls per plant, and significantly more than any of the other varieties. Lot 520, for example, may be considered to be quite superior to these two in having 20 galls less per plant 6 months after inoculation started. Some of the other varieties show even greater differences. It should be reasonably safe to assume that environmental resistance would be fairly uniform for all of the containers

except for one factor. This factor is the matter of difference in the number of roots, especially the fine lateral and fibrous roots, possessed by each variety Plants with an abundant supply of these roots, it is thought, should pick up more nematodes from the soil infestation, thus resulting in fewer large galls in the main roots. But there seems to be no such relationship between number of roots, nematode inoculation, and galls. Lot 520 has the greatest number of fibrous roots, Cayenne and Hilo next, and Ruby and Taboga have comparatively scanty root systems. Yet Ruby and Taboga show the fewest galls in the main roots, Lot 520 almost as many, and Cayenne and Hilo possess three times as many as the first two mentioned. The amount of inoculum added to the soil was not excessive, judging by field conditions, and none of the varieties of plants reached a saturation point in the number of galls that could be formed in the roots.

Apparently the two varieties being grown commercially in the Hawaiian Islands are contributing the largest number of galls from a given inoculation, at the end of 6 months of growth following inoculation. No doubt, the continued planting of Cayenne and Hilo varieties is an important factor in the production of large nematode populations in Hawaiian pineapple soils. It is an interesting speculation, whether Ruby, Taboga, Wild Kailua, or some other variety having comparatively fewer galls from a given inoculum, as shown by this test, would maintain the present high nematode populations that we find when Cayenne and Hilo are grown.

A possible solution of the nematode problem

The evidence already presented is believed to have shown that amount of infection and degree of root damage to pineapples are not highly, if at all, correlated when different varieties are compared. Tolerance or resistance to nematode attack is, therefore, presumably a physiological property of the plant variety. Should it later prove to be merely a physical stoppage of root growth, the value of the present discussion is not necessarily impaired, for the varieties do exhibit marked differences in the visible amount of reduction in root length due to nematode attack.

Cayenne and Hilo varieties are seriously curtailed in root development when nematodes are present in their roots. On the contrary, Lot 520 seems to show very little, if any, root loss due to their influence. Lot 520 is a hybrid whose male parent is Wild Brazil, a plant which appears to be quite tolerant to this species of nematode. The other parent is the commercial Cayenne, a much less tolerant variety. Evidently, tolerance is a genetic factor, or complex of factors, which distinguishes certain varieties from others.

Lot 520 is not a commercial type, but the triploid hybrids, having 50 Cayenne and 25 Wild Brazil chromosomes, show some promise of commercial value. Further, there is no reason to suppose that its tolerance to nematodes would be lost if it owes this factor to actual genetic differences in its chromosomes. Continued hybridization, especially back-crossing, may eventually produce a

highly tolerant, yet commercially desirable plant. Such an individual once obtained, either by these crosses or by others, would establish a clon whose perpetuation and extensive vegetative multiplication would greatly relieve the pineapple industry of the necessity of considering this parasite seriously.

SUMMARY AND CONCLUSIONS

Eight varieties of pineapples have been examined for numbers of galls produced in their roots by the nematode, *Heterodera radicicola*. None is immune to attack.

Comparisons are based on numbers of non-terminal, terminal, and total galls; also on galls per root, and galls per foot of root length. The numbers of significant differences in the 28 possible comparisons in each classification are as follows: for non-terminal galls, 9; terminal galls, 22; total galls, 20; galls per root, 7; galls per foot of root length, 4.

There are few significant differences in the number of non-terminal galls, but some varieties, as Natal, seem to continue root growth in spite of nematode attack, thus producing a comparatively large number of these galls. The actual number per variety appears to vary with root length. All but one of the significant differences agree with terminal gall differences in comparing the same varieties.

A terminal gall is formed when root growth ceases upon invasion of the root tip by nematodes. The different varieties vary greatly in the number of these galls upon their roots. The actual number in each variety seems to depend upon the number of roots possessed by the plant. There are, also, more significant differences in this classification than in the others. From 54 to 77 per cent of all galls fall into the terminal gall class, depending upon the variety.

Comparisons of total number of galls show 20 significant differences in this classification compared with 22 terminal gall differences. Nineteen of these duplicate terminal gall comparisons. In every terminal gall comparison, whether significant or not, any variety having more terminal galls than another also will be found to exceed the other in the total number of galls, except in the Natal-Pernambuco comparison where the former has fewer terminal galls, yet exceeds Pernambuco in total galls.

In number of galls per root there are 7 significant differences in 28 comparisons. Comparisons in number of galls per foot of root length show only four significant differences. These few differences emphasize the fact that, after all, the infection occurring in all varieties is noticeably uniform when the extent of the root systems possessed by each variety is taken into account. From this it follows that all varieties are about equally susceptible to attack, as those varieties having the greatest root lengths show more galls.

The different varieties apparently do not respond alike to nematode attack when Rank-Difference correlations are used to determine the correlation between average reduction in root length per plant and numbers of terminal galls, total galls, galls per root, or galls per foot of root length. At least such indexes of

correlation are very low. The amount of root length reduction expresses differences between varieties in their relative tolerance, or lack of tolerance, to nematode attack.

Some of the varieties developed three times as many galls within 6 months as did others. It is assumed that populations varied according to the number of galls which appeared in this length of time. Cayenne and Hilo bore the greatest number of galls at the close of the experiment. It would seem that these two varieties are an important factor in maintaining the present high nematode population in Hawaiian field soils.

Tolerant hybrids which show little influence of nematode attack have already been developed and it is thought that a possible solution of the nematode problem might come through the application of genetic principles in nematological investigation.

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THE ELECTROMETRIC DETERMINATION OF CHLORIDES IN SOILS BY THE SILVER-SILVER CHLORIDE ELECTRODE

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Heretofore, the determination of chlorides in soils has been made by the gravimetric or volumetric procedure, either procedure, however, necessitating the preparation of the soil extract.

The application of the silver-silver chloride electrode to the determination of chlorides offers the advantage of greater rapidity, in that the determination may be made on the soil suspension or extract. The turbidity factor and uncertainties attending the use of an indicator, as in the volumetric procedure, are also eliminated.

The present investigation presents a comparison of results obtained by the silver-silver chloride electrode and the silver chromate methods.

THEORETICAL CONSIDERATIONS

Adopting a procedure similar to that used by Cavanagh (2), Best (1) applied the Ag-AgCl electrode to the determination of chlorides in Australian soils using a quinhydrone electrode as a reference electrode, the pH value of which may be calculated as follows:

The equation for the potential difference of an Ag-AgCl electrode in a solution containing chloride ions is:

$$(A) \qquad E_{Ag} = E'_{Ag} - \frac{RT}{F} ln\ [Cl^-]$$

the constant E'_{Ag} having the value 0.2221 volts at 25°C. (5). The value of $[Cl^-]$ at the end-point in the titration of a chloride solution with silver nitrate is taken as 1.30×10^{-5} at 25°C. (4), namely, the solubility of silver chloride in water. Inserting these values in equation (A) gives for E_{Ag} the value 0.5109 volts at 25°C. If an Ag-AgCl electrode is in combination with a quinhydrone electrode of the same potential then at the end-point of the titration the potential difference between two such electrodes should be zero. The pH value of the buffer solution used as the quinhydrone electrode may be computed from equation (B) by equating to zero potential, or by substitution in the working equation for the quinhydrone electrode.

$$(B) \qquad E = E_q - E'_{Ag} + .05912 \log [H^+]\ [Cl^-], \text{ at } 25°C.$$

The pH value of this buffer solution is calculated to be 3.18 for 25°C. The lower value, pH 3.03 at 25°C. calculated by Best (1), is due to the use of different values for E'_{Ag} and the solubility of silver chloride. If the buffer solution had a pH value of 3.4 at 25°C. zero potential would occur at pCl 4.66 instead of at the correct pCl 4.89. In 50 ml. the correct titre would necessitate the further addition of 0.025 ml., about one-half of a drop of $N/35.457$ silver nitrate. From Cavanagh's data (2) the pH value of the buffer solution at 16°C. is 3.25. It is evident that a buffer solution of pH 3.1 to 3.3 is sufficiently accurate.

With the addition of silver nitrate the potential decreases until at the end-point it becomes zero when with further addition of silver nitrate (within one drop) the polarity reverses.

METHODS OF EXPERIMENTATION

Preparation of the silver-silver chloride electrode

The Ag-AgCl electrodes designed by the writer were made by winding one end of a thin platinum wire about 3 cm. long around the end of a silver wire about 1 mm. in diameter and about 5 cm. long and heating the joint with a blast lamp until the silver wire just fuses to the platinum wire. The platinum end including the joint was inserted into a narrow glass tube constricted about one-half inch from the end and permitting the passage of the platinum wire up to the joint. The platinum wire was sealed in at the constriction so that a portion extended above the seal, permitting the customary mercury contact. About 3 to 4 cm. of the silver wire extended from the end of the tube and was sealed at this point with DeKhotinsky cement. The cleaned wire was coated with silver chloride by making it the anode in the electrolysis of a dilute solution, about 0.1 N potassium or sodium chloride, using a current density of 2 to 3 milliamperes per square centimeter for about one hour. The current was supplied by a 4-volt storage cell by the insertion of sufficient resistance. The used electrodes were cleaned with ammonium hydroxide and polished with a very fine abrasive, such as crocus cloth, and then thoroughly washed.

Preparation of the quinhydrone electrode

A KHPhthalate-H_2SO_4 buffer solution free from chlorides was used for the quinhydrone electrode and was prepared as described by Clark (3) but with the substitution of sulfuric acid for hydrochloric. The buffer solution has a calculated pH value of 3.18 at 25°C.; however, a pH value of 3.1 to 3.3 at 25°C. is sufficiently accurate. The quinhydrone electrode was prepared by adding about 0.05 gm. of quinhydrone to about 15 ml. of the buffer solution, in a test tube.

Apparatus

A platinum foil electrode and one end of a U-shaped agar bridge, held in place by a rubber stopper, made contact with the quinhydrone electrode.

The other end of the agar bridge passed through a rubber stopper holding the Ag-AgCl electrode. The agar bridge was made by heating a 5 per cent agar solution saturated with potassium nitrate, drawing into a dry U-shaped tube, and allowing to cool.

In the present work a potentiometer was used, the quinhydrone and Ag-AgCl electrodes being connected to the positive and negative terminals respectively. Prior to an electrometric determination it is advisable to check the system by titration of a definite volume of $N/35.457$ potassium chloride made up to 50 ml.

Procedures

When employing the electrometric procedure described by Best (1), the results obtained on some of the soils in table 1 were too high because of the drifting back of the end point. This necessitated further increments of silver nitrate in excess until the end point remained constant. In Best's procedure no mention is made concerning the reaction of the soil suspension. It was found, however, that unless the reaction of the soil suspension was adjusted to about pH 2.0 the results in many cases were in error. By adjusting the reaction of the suspension to about pH 2.0 any effect of carbonates on the titration is also eliminated. Constant stirring by an electric stirrer was found preferable to stirring with a glass rod after each addition of reagent as recommended by Best.

The electrometric procedure adopted is as follows:

To a 150-ml. beaker were added 5 gm. of soil, passing a 50-mesh sieve, and 50 ml. of distilled water. The sample was increased to 10 gm. for small amounts of chlorine and decreased for large amounts. When the soil extract was being used an aliquot was made up to approximately 50 ml. with distilled water. The Ag-AgCl electrode and agar bridge were allowed to reach nearly to the bottom of the beaker and the suspension was continually stirred by an electric stirrer during the determination. Sufficient sulfuric acid (1 + 2) was added dropwise to the suspension or extract to just redden a strip of thymol blue paper, about pH 2.0, and this reaction was maintained. At the end of 10 minutes the circuit was momentarily closed and the galvanometer deflection observed, from which an approximation may be had of the volume of $N/35.457$ silver nitrate required. During the course of a titration, particularly on the soil extract, it may be necessary occasionally to wash the electrode free from any adhering silver chloride. Silver nitrate is added, with subsequent adjustment of the potentiometer, until the galvanometer deflection just reverses, indicating the end-point. It is desirable to continue the determination 5 minutes longer to be sure the end-point is constant. The silver nitrate solution is made up as $N/35.457$ so that 1 ml. is equivalent to 1 mgm. of chlorine. An $N/35.457$ potassium chloride solution may be used for back titration if necessary.

For preparing the soil extract a soil-water ratio of 1 to 5 was shaken in a 250-cc. pyrex centrifuge bottle in an end over end shaker for 1 hour. The suspension was allowed to stand for a while to permit sedimentation and then filtered through a Mandler filter, care being taken to discard the first portion of the extract, because of the absorptive effect of the filter which causes a slight concentration change in the solution.

For the silver chromate method an aliquot was neutralized and titrated with $N/35.457$ silver nitrate, potassium chromate being used as an end-point indicator.

RESULTS

The results obtained by the Ag-AgCl electrode on the soil suspension and extract and by the silver chromate method on the extract are presented in table 1. These soils varied in reaction from about pH 3.4 to 10.5, and included peats, mucks, clays, loams and silty clay, clay, silt, and fine sandy loams from Arizona, California, Colorado, Indiana, Maryland, Missouri, New Jersey, New York, Ohio, South Carolina, and Texas.

With the exception of soil number 5 the agreement between the different methods is very good. In this instance the result on the suspension by the

TABLE 1

Chloride results on soils determined by the Ag-AgCl electrode and silver chromate methods

NUMBER	Ag-AgCl ELECTRODE		SILVER CHROMATE METHOD—EXTRACT	NUMBER	Ag-AgCl ELECTRODE		SILVER CHROMATE METHOD—EXTRACT	NUMBER	Ag-AgCl ELECTRODE		SILVER CHROMATE METHOD—EXTRACT
	Suspension	Extract			Suspension	Extract			Suspension	Extract	
	per cent Cl	*per cent* Cl	*per cent* Cl		*per cent* Cl	*per cent* Cl	*per cent* Cl		*per cent* Cl	*per cent* Cl	*per cent* Cl
1	0.004	0.004	0.004	17	0.043	0.040	0.042	33	0.175	0.170	0.175
2	0.006	0.005	0.005	18	0.044	0.042	0.047	34	0.185	0.180	0.185
3	0.006	0.005	0.006	19	0.042	0.046	0.048	35	0.220	0.215	0.215
4	0.006	0.005	0.007	20	0.055	0.052	0.056	36	0.241	0.239	0.243
5	0.017	0.008	0.009	21	0.072	0.069	0.069	37	0.244	0.248	0.251
6	0.009	0.008	0.009	22	0.072	0.068	0.071	38	0.273	0.268	0.271
7	0.018	0.015	0.016	23	0.072	0.069	0.071	39	0.256	0.270	0.275
8	0.016	0.016	0.018	24	0.080	0.081	0.084	40	0.325	0.325	0.329
9	0.021	0.019	0.021	25	0.085	0.081	0.085	41	0.417	0.412	0.414
10	0.028	0.027	0.028	26	0.082	0.083	0.086	42	0.454	0.450	0.455
11	0.033	0.027	0.028	27	0.119	0.117	0.121	43	1.298	1.282	1.290
12	0.034	0.031	0.032	28	0.126	0.127	0.129	44	1.419	1.410	1.415
13	0.034	0.034	0.035	29	0.144	0.138	0.144	45	1.493	1.502	1.515
14	0.036	0.035	0.035	30	0.147	0.149	0.152	46	1.574	1.588	1.609
15	0.036	0.038	0.040	31	0.150	0.152	0.151	47	2.083	2.090	2.100
16	0.039	0.040	0.042	32	0.168	0.165	0.168	48	2.104	2.121	2.143

Ag-AgCl electrode was higher than the Ag-AgCl electrode and silver chromate results on the extract, the latter two results, however, being in excellent agreement. During the titration of this suspension the galvanometer deflection, when adjusted to zero after silver nitrate was added, would drift back, corresponding to an increase in potential and indicative of an increase in the chloride-ion concentration.

A temporary end-point was reached but the deflection gradually reversed again, necessitating further additions of silver nitrate in excess of the correct titre until at last a constant end-point was reached. With this soil the tendency to drift was more pronounced without the addition of sulfuric acid.

Such a tendency for the galvanometer to drift was observed among some of the other soils in table 1, when the addition of sulfuric acid to the suspension was omitted, but by maintaining the pH value at about 2.0, the drifting was eliminated and the results were in good agreement. This tendency to drift, however, was not observed during the electrometric determination on any of the extracts. With soils such as number 5 where the electrometric result on the suspension was too high as indicated by the behavior of the galvanometer, the electrometric result on the extract, however, shows good agreement with the silver chromate result.

In regard to the effect of organic matter on the determination, Best (1) applied the method to Australian soils low in organic matter and to one soil of high humus content and found good agreement between the electrometric and

TABLE 2

Organic matter in soils

NUMBER	ORGANIC MATTER	NUMBER	ORGANIC MATTER	NUMBER	ORGANIC MATTER
	per cent		*per cent*		*per cent*
2	9.29	17	0.74	36	0.52
5	5.21	21	0.31	37	3.99
7	3.97	23	0.93	38	9.29
9	53.0	29	0.36	39	6.71
10	0.14	30	0.28	40	0.83
11	1.89	31	0.14	41	8.77
12	3.15	32	0.86	42	0.71
13	0.26	33	0.14	43	0.65
14	0.40	34	0.10	44	6.62
15	2.55	35	0.41	45	7.91

silver chromate methods. The organic matter[1] was determined on most of the soils in table 1, and the results are presented in table 2.

Two peat soils not included in table 1 showed very good agreement between the Ag-AgCl electrode and silver chromate methods. There is apparently no relationship between the anomalous behavior of soil number 5 and the total organic matter, in view of the fact that other soils in table 2 containing larger amounts of organic matter showed good agreement between the two methods. Soils number 5 and 7 were the same soils but number 5 had just been mixed for greenhouse use, whereas number 7 had been in use five or six weeks. The results in table 1 on number 7 are, however, in very close agreement. After soil number 5 was treated with about 30 per cent hydrogen peroxide, the drifting as previously described was absent during the electrometric determination and the result in this instance agreed very closely with the electrometric and silver chromate results, on the water-soluble extract, given in table 1.

[1] The author expresses his appreciation to W. R. Leighty of this laboratory for the organic matter determinations.

SUMMARY

The application of the Ag-AgCl electrode to the determination of chlorides in the soil suspension or extract is described.

Good agreement was found between the results obtained by the Ag-AgCl electrode method, on the soil suspension and extract, and the silver chromate method on the extract.

The advantages of the electrometric method are its rapidity and the elimination of the turbidity factor and of the use of an indicator.

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BASE INTERCHANGE INDUCED BY CALCIUM, MAGNESIUM, AND SODIUM NITRATES IN A 6-FOOT COLUMN OF SOIL-SUBSOIL

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It was shown by Mooers, MacIntire, and Young (3) that when heavy equivalent additions of sodium, calcium, and magnesium nitrates were made to a Cumberland clay loam, there was a marked difference in the speed with which the NO_3 ion passed through the 5-foot underlying depth of clay subsoil. The outgo of nitrates from the sodium nitrate addition was much more rapid than that from the equivalent amounts of either calcium or magnesium nitrate. The nitrate recovery was considered without reference to the cation combination. The present paper shows the base exchange that was induced by each of the three nitrates during a 9-year period of leaching by natural rainfall.

EXPERIMENTAL

Soil and placement. The leachates were from an 8-inch depth of soil underlaid by five 1-foot demarcated layers of a red clay subsoil in lysimeters of 12-inch diameter and 1/55,462-acre area. The surface soil was a Cumberland clay loam that had never been limed. It was a well-buffered soil, containing 22 per cent colloids. The pH values of the soil and subsoil were 6.84 and 6.40, respectively. The amounts of acid-soluble and exchangeable bases in both soil and subsoil are shown in table 1.

The tanks were filled December 15, 1921. A layer of gravel, topped by a layer of coarse quartz, was first introduced. Upon this was placed a 1-foot depth of $\frac{1}{4}$-inch sifted moist clay in two equal fractions. Fifteen tamps were given each successive 6-inch layer by means of a circular tamp that covered the entire subsoil surface. The successive 1-foot depths were separated by discs of asphaltum-coated, $\frac{1}{8}$-inch galvanized iron wire "cloth." The moisture-free weight of each soil charge was 39.27 pounds. The respective m.f. weights of the first- to fifth-foot layer of subsoil were, *52.26*, *52.23*, *48.21*, *48.39*, and *52.56* pounds.

Nitrate additions. The tanks were allowed to leach without additions until May 9, 1922, the rainfall during that period being 27.4 inches. The original objective was to determine the recovery and the speed of the movement of the nitrate ion through clay subsoil. Previous studies had indicated that the nitrate recoveries from sodium nitrate were obtained largely as calcium and

magnesium nitrates. These two nitrates were therefore run in parallel with sodium nitrate. The plan called for single equivalent additions of the three nitrates at the rate of 600 pounds of $NaNO_3$, the solutions of the three salts to be applied to the soil surface. Through an error in decimal place in the computations, the additions were made at the constant rate of 6,000 pounds of $NaNO_3$. It therefore seemed probable that treatments so heavy would effect exchange reactions of sufficient magnitude to register definitely in the percolates. The

TABLE 1

Acid-soluble and exchangeable bases in Cumberland loam and red clay subsoil, m. f. basis

COMPONENT	ACID SOLUBLE*		EXCHANGEABLE†	
	Soil	Subsoil	Soil	Subsoil
	per cent	*per cent*	*per cent*	*per cent*
CaO as $CaCO_3$ ⇔	0.278	0.140	0.092	0.033
MgO as $CaCO_3$ ⇔	0.657	1.041	0.011	0.023
K_2O	0.265	0.396	0.010	0.014
Na_2O‡	0.016	0.020	0.0013	0.0023

* HCl 1.115 digestion.

† Ca, Mg, and K, leaching with normal solution NH_4Cl; Na, leaching with 0.05 *N* HNO_3.

‡ Direct method, Caley and Foulk (3).

TABLE 2

Calcium, magnesium, and potassium interchange in a 6-foot depth of soil-subsoil as induced by single equivalent additions of nitrates of sodium, calcium, and magnesium during a 9-year period*

ADDITION	$CaCO_3$ ⇔, LEACHED, POUNDS PER ACRE SURFACE, FROM 8-IN. SOIL AND 5-FT. SUBSOIL					
	Calcium		Magnesium		Potassium	
	Found	Exchanged	Found	Exchanged	Found	Exchanged
None	989	...	540	...	118	..
Sodium nitrate	1,319	330	825	285	185	67
Calcium nitrate	1,862	873†	1,615	790	164	46
Magnesium nitrate	1,960	971	1,604	779†	156	38

* Constant of 6,000 pounds of $NaNO_3$.

† Derived from the addition.

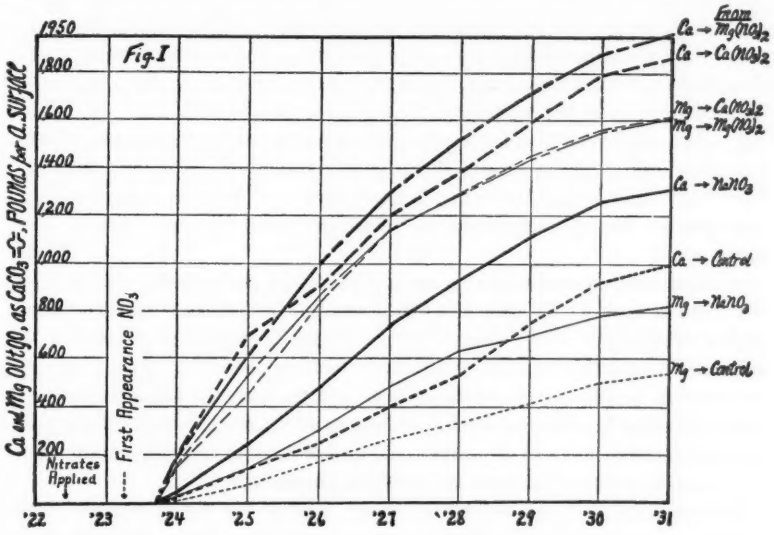
dissolved nitrate additions were made May 9, 1922, after a preliminary settling period of 145 days. Three tanks were used for the untreated control and three for each of the nitrate additions.

Ratio of rainfall to leachings. The rainfall for the 9-year period, May 9, 1922, to May 8, 1931, was 445.52 inches, or an annual average of 49.50 inches. The rainfall recoveries, as averages for the triplicated units for each treatment, were: control 64.18 per cent; calcium nitrate 64.88 per cent; magnesium nitrate 64.43 per cent; and sodium nitrate 65.98 per cent. The rapidity of the movement

may have been influenced by the specific treatment, but there was little difference between the ultimate amounts of the percolates.

Leachates. The first enhancement in nitrate outgo appeared in the percolates collected between January 3 and April 18, 1923. Beginning with the next collection, the outgo of calcium, magnesium, and potassium was determined. The totals of Ca, Mg, and K, obtained by averaging each 3-unit series, are given in table 2. The cumulative outgo for calcium and magnesium by annual periods is given in figure 1, in terms of $CaCO_3$ equivalence, pounds per acre.

Calcium outgo. The outgo of calcium induced by the magnesium nitrate addition was considerably greater than that found for the addition of sodium



nitrate. The enhanced outgo of calcium from the calcium nitrate addition was 98 pounds $CaCO_3$ eq. less than the amount forced by the magnesium nitrate from the column of soil-subsoil during the 9-year period. Considering the large factor used to convert the outgo from the small tanks to the acre-surface basis, the quantity of calcium recovered from the calcium nitrate addition and that exchanged by the magnesium of the magnesium nitrate addition may be considered as equivalent.

Magnesium outgo. The enhancement of magnesium outgo from the addition of magnesium nitrate is practically the same as that induced through interchange between the added calcium and the soil magnesium. The replacement of magnesium by the sodium of the sodium nitrate addition was decidedly less than the replacement shown for the calcium of the calcium nitrate addition. The reciprocal effect of the calcium and magnesium nitrates in liberation of

magnesium and calcium and the decidedly lesser activity of sodium nitrate demonstrate that the di-valent cations were much more effective than the mono-valent Na. It will be noted that the amount of exchangeable calcium in the surface soil is more than eight times that of magnesium, whereas the ratio in the subsoil is 1.45 to 1. The greater part of the exchanged magnesium was therefore probably derived from the 5-foot depth of subsoil.

Potassium outgo. The outgo of potassium from each of the three added nitrates was greater than that found for the three control tanks, but no extensive liberation of potassium was evidenced. The increases in potassium outgo were only small fractions of the liberations shown for calcium and magnesium, even though the amount of exchangeable K_2O in the surface soil was practically the same as that of MgO. The amount of exchangeable potassium in the subsoil was 61 per cent of the exchangeable magnesium. When considered as 9-year totals, the apparently greater activity of sodium nitrate in effecting potassium exchange is not convincing, and the enhancements in potassium outgo may be considered as in fair agreement for the three nitrate additions. The indicated exchanges must be considered as the total effect of the full 6-foot depth of soil and subsoil, so that a greater liberation of potassium in the upper zones may have been offset by a fixation in the lower zones. If this did take place the phenomenon was different from the effect registered by both calcium and magnesium.

With so small an exchange of potassium shown for the excessive additions of the three nitrates at the rate of 6,000 pounds of $NaNO_3$ = with their mass-action capacity, it would seem that the actual liberation of potassium by economic additions of nitrates is not likely to be appreciable. This conforms to previous findings as to the activity of sulfates with the same surface soil alone (2) where 4,250-pound $CaSO_4$-equivalent additions of ferrous sulfate gave a marked enhancement in the outgo of sulfates of calcium and magnesium, with only a small increase in the amount of potassium leached.

Sodium outgo. Since a dependable direct method for the determination of sodium was not available when the experiment was begun, the difference between the total sulfates and the sum of the sulfates of calcium, magnesium and potassium was taken as the sodium sulfate equivalent of the sodium leached. The results so obtained were considered as qualitative, or at least only approximate, and they will not be given in detail. The direct determination of exchangeable sodium in the soil and subsoil by use of the sodium-magnesium-uranyl acetate method (1) shows the low occurrences of 0.0013 per cent and 0.0023 per cent for soil and subsoil, respectively.

If the sodium determinations be considered as only approximately correct, the increases found for sodium outgo from the additions of calcium, magnesium, and sodium nitrates were 2.8 per cent, 29.6 per cent, and 94.2 per cent, respectively. This greater outgo of sodium from the sodium nitrate addition fits in with the finding that the amount of calcium replaced by magnesium nitrate and

the amount of magnesium replaced by calcium nitrate were decidedly less than the replacements of calcium and magnesium shown for sodium nitrate.

SUMMARY

Triplicated single, heavy, equivalent additions of sodium, calcium, and magnesium nitrates were made to Cumberland clay loam underlaid by 5 feet of red clay subsoil, and the outgo of bases was determined annually for a period of 9 years in 12 lysimeters.

The replacements of calcium and magnesium by sodium were decidedly less than the reciprocal calcium-magnesium replacements shown for the two di-valent nitrates.

The amounts of calcium recovered from calcium nitrate and exchanged by the magnesium of magnesium nitrate were practically the same. Conversely, the recovered and exchanged quantities of magnesium from magnesium nitrate and calcium nitrate, respectively, were in close agreement.

The amounts of potassium replaced by the heavy additions of sodium, calcium, and magnesium nitrates were so small as to indicate that the amounts of potassium made available by ordinary amounts of nitrates would be inconsequential.

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SOIL ACIDITY AS A PHYTOPEDOLOGICAL FACTOR[1]

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The old Russian school of soil scientists thoroughly worked out the principles of genetic pedology based chiefly on morphological and but partly on chemical properties of soil horizons. In more recent years, as a result of investigations in the United States, in England, in Germany and elsewhere, on the rôle of microörganisms in the soil, an extensive and very fruitful biological trend was created in soil science, while by ascertaining the rôle and importance of the soil absorbing complex, a new branch of science, which can easily be termed soil physiology, has been created.

But the surface vegetation has been, so far, studied mainly by botanists, and consequently, its importance as a factor in soil formation has appeared to be of less significance than it really is. Because soils were studied independently from plants we failed to appreciate the laws governing the close relationship between plants and soil, which exists in nature.

And since all problems of agronomy may eventually be reduced to the question of the relationship between plants and soil, the importance of the said branch of science becomes most obvious.

Forest associations in virgin regions such as Siberia represent a most convenient object for the studying of this question. The author believes that the existence for many centuries of these associations on the same site, as well as their natural succession, would provide some indications whereby we could be guided in regard to those laws which form the basis of the mutual relationship of the plant and the soil.

In fulfillment of the program of work planned, the author contrived to collect from elevated forest regions on the eastern and southern coast of the Baikal Lake, a considerable quantity of soil samples of diverse horizons. These samples were used by the author during his studies on the relationship between Siberian forest associations and the soil.

After perusal of the literature, we have ascertained that, notwithstanding considerable research work in this connection, we may assume that only one fact has been proved, i.e., forest association stands succeed each other in a certain definite order.

It has not been possible, however, to establish the reason for such a sequence,

[1] Translated from the Russian by U. G. Andronikov.

or even to connect the character of the alteration of cover types with that of the alteration of soils.

As the author is not aware of any work dealing with all forms of acidity of soil profiles in connection with cover types, he has decided to determine, in numerous samples of East Siberian forest soils, not only the concentration of hydrogen ions but the exchangeable and hydrolytic acidities as well.

In these latter forms the author hoped to find a settlement of the question which was of interest to him, as these forms are more responsive than the pH to changes that take place in the soil.

The hydrolytic acidity is the weakest form of general soil acidity. When the exchangeable acidity is hardly detectable noticeable amounts of the hydrolytic form are always present. The deterioration of the soil affects, in the first place, the increase of the hydrolytic acidity.

A stronger form—the exchangeable acidity—arises in the soil with great difficulty. The exchangeable acidity being unchangeable, the increase of hydrolytic acidity shows that the process of soil oxidation is still in the first stage of its development. Under conditions of an anergetic and prolonged effect of the oxidizing factor, an increase both of the hydrolytic and the exchangeable acidity may be expected, with a noticeable decrease in the latter's value. Consequently, in various correlations of these values we may detect different rates of increase of soil acidity.

If we maintain that the hydrolytic form of acidity is its weakest form, we must recognize that the opposite process—the decrease of soil acidity—must again affect its hydrolytic form and alter the correlation of these forms, reversing them; that is, the exchangeable acidity being unchangeable, the hydrolytic form decreases. Under conditions of the stability of physico-chemical processes in the soil, the correlation of values of these forms of acidity may be more or less constant.

All the foregoing contentions, which are experimentally proved in this paper, have been taken by the author as a basis for his studies on the character of the effect of various tree associations on the soil.

METHODS OF DETERMINING SOIL ACIDITY

A 100-gm. sample of air-dried soil was shaken for 1 hour in a Wagner apparatus with 250 cc. of 7.5 per cent potassium chloride. The solution was then filtered and titrated with 0.1 *N* sodium hydroxide. A special 100-gm. sample was treated under similar conditions with a 13.5 per cent solution of sodium acetate. The concentration of hydrogen ions was determined in potassium chloride solution and, consequently, shows not only free hydrogen ions but those absorbed by the soil complex, which in this case are supplanted by potassium ions.

The acidity of the extract, determined by titration with KCl solution, we designate "exchangeable" acidity, and that with sodium acetate solution—"hydrolytic" acidity.

TABLE 1

pH values of the exchangeable and hydrolytic acidities of soil under various forest associations

Constant forms of phytopedological relations

NUMBERS OF SAMPLES	COVER TYPES	pH	EXCHANGEABLE ACIDITY*	HYDROLYTIC ACIDITY*	HORIZON	REMARKS
23	Fir-cedar	3.4	26.0	220.0	A	
29	Fir-cedar	3.6	88.4	154.7	A	
21	Fir-cedar	3.6	10.1	147.5	A	
22	Fir-cedar	3.9	54.2	107.5	A	
13	Fir-cedar	3.9	26.5	253.5	A	
17	Fir-cedar	3.9	21.1	109.7	A	
121	Fir-cedar	3.7	18.5	345.0	A	
115	Fir-cedar	4.0	26.6	116.5	A	
116	Fir-cedar	3.8	12.5	223.5	A	
35	Fir-cedar	3.7	32.0	160.2	A	
105	Fir-cedar	3.9	31.5	145.2	A	
Mean.....		3.8	31.0	180	A	
23	Fir-cedar	4.6	10.6	32.3	B	
105	Fir-cedar	4.3	31.5	70.0	B	
119	Fir-cedar	4.1	58.0	93.7	B	
29	Fir-cedar	4.1	48.8	70.0	B	
Mean.....		4.3	35.0	66.0	B	
1	Cedar-larch	4.1	32.0	136.0	A	
3	Cedar-larch	4.0	19.1	98.0	A	
61	Cedar-larch	4.1	60.0	192.0	A	
62	Cedar-larch	4.2	43.2	115.5	A	
4	Cedar-larch	3.9	26.0	89.0	A	
Mean.....		4.1	36.0	126.0	A	
1	Cedar-larch	4.2	14.0	44.0	B	
3	Cedar-larch	3.8	37.0	55.7	B	
4	Cedar-larch	3.8	34.0	62.0	B	
61	Cedar-larch	4.0	77.2	108.0	B	
62	Cedar-larch	4.1	36.5	88.0	B	
Mean.....		4.0	39.7	71.5	B	
46	Fir	4.3	16.5	44.0	A	
68	Fir	4.2	12.0	179.0	A	
112	Fir	4.5	6.0	175.0	A	
Mean.....		4.3	11.5	130.0	A	
46	Fir	4.8	5.5	22.0	B	
68	Fir	4.9	1.5	60.2	B	
112	Fir	4.6	23.2	69.2	B	
Mean.....		4.8	10.0	50.5	B	

* In this table and in tables 2 and 3, the values of the exchangeable and hydrolytic acidity are given in cubic centimeters per 100 gm. of soil and are results of the first titration without multiplication by coefficient.

TABLE 1—*Continued*

NUMBERS OF SAMPLES	COVER TYPES	pH	EXCHANGEABLE ACIDITY*	HYDROLYTIC ACIDITY*	HORIZON	REMARKS
24	Cedar	4.4	16.7	39.5	A	
25	Cedar	4.2	12.7	75.7	A	
48	Cedar	4.4	8.0	116.7	A	
102	Cedar	4.6	4.5	176.0	A	
103	Cedar	4.9	1.7	92.5	A	
104	Cedar	4.3	5.7	145.5	A	With birch
124	Cedar	4.2	15.7	293.0	A	With fir
127	Cedar	4.2	51.2	127.0	A	With A_0
49	Cedar	4.8	3.5	93.5	A	
Mean.....		4.4	12.5	128.8	A	
127	Cedar	4.6	15.7	51.5	B	
49	Cedar	4.3	12.0	34.0	B	
25	Cedar	4.6	8.2	31.7	B	
Mean.....		4.5	12.0	39.0	B	
52	Birch	5.5	2.0	91.0	A	
53	Birch	5.1	1.2	93.0	A	
136	Birch	6.0	1.7	80.0	A	
45	Birch	5.9	1.0	85.0	A	
Mean.....		5.6	1.5	87.0	A	
45	Birch	5.4	1.7	25.5	B	
52	Birch	5.4	7.5	38.5	B	
53	Birch	5.4	9.5	37.5	B	
Mean.....		5.4	6.2	33.8	B	
75	Aspen	6.6	0.2	13.8	A	Shady aspen
76	Aspen	6.3	0.4	11.8	A	
134	Aspen	6.1	0.8	61.0	A	
133	Aspen	5.5	1.5	67.5	A	Young aspen grove
Mean.....		6.1	0.7	35.0	A	
134	Aspen	6.6	10.0	32.5	B	
75	Aspen	6.7	1.0	3.7	B	Shady aspen
76	Aspen	6.5	1.0	7.0	B	
Mean.....		6.6	4.0	14.4	B	
57	Pine, larch	6.2	0.4	30.4	A	
58	Pine, larch	6.2	0.7	51.7	A	
82	Pine, larch	6.4	0.3	19.2	A	
26	Pine, larch	6.3	0.5	32.7	A	
32	Pine, larch	6.3	0.5	30.9	A	
Mean.....		6.3	0.5	33.0	A	

TABLE 1—*Concluded*

NUMBERS OF SAMPLES	COVER TYPES	pH	EXCHANGEABLE ACIDITY*	HYDROLYTIC ACIDITY*	HORIZON	REMARKS
128	Poplar	6.6	2.0	26.5	A	
128	Poplar	6.5	0.75	4.7	B	
77	Larch-pine	6.7	0.5	11.0	A	
79	Larch-pine	6.6	1.5	12.0	A	
Mean.....		6.6	1.0	11.5	A	
77	Larch-pine	6.4	0.75	6.75	B	
79	Larch-pine	6.7	1.0	5.5	B	
Mean.....		6.6	0.8	6.1	B	
55	Pine	6.7	1.5	6.5	A	
55	Pine	6.4	1.0	17.5	B	
57	Pine	6.3	2.5	10.5	B	
Mean.....		6.4	1.7	14.0	B	

The concentration of hydrogen ions was determined colorimetrically, according to Michaelis' method.

The results of our studies on the acidity of soils in connection with cover types growing on them are shown in tables 1 and 2.

From these data we are justified in drawing a general inference that each type of associated forest tree is in strict relationship with the soil on which it grows. The relationship is mutual, i.e. one should not imagine that cover types use only types of soils, or varieties, formed under the influence of geological, climatic, and other conditions not of a biological character.

The soil on which a certain cover type grows is a direct result of the latter's life activity,—a resultant of the effect of centuries upon the mineral substrate.

Genetic pedology usually understands under the idea "forest soils" only a podzolization process, which is far from corresponding to the variability which we have found in the physico-chemical condition of the soil under various cover types.

Each forest association has its specific effect upon the soil and creates a special type, or rather, a biotype. We find it, therefore, necessary to introduce a concept in which there should be embodied not only any one particular type of soil but also the type of vegetation which formed it. These shall be "phytopedological classes," which comprise definite groups of associations. Each phytopedological class, as well as the groups of which it consists, possesses its own class index.

Our conviction that the principles by which we were guided in proposing the introduction of a phytopedological system are correct, was fortified, especially when, after computing table 3, we applied it to the analysis of certain phenomena. Some soil samples among those we had studied could not be classed according to our standards; however, when we applied a phytopedological interpretation to them, the discrepancies in acidity values were definitely explained.

TABLE 2

Transition forms of phytopedological relations

NUMBERS OF SAMPLES	COVER TYPE	pH	EXCHANGEABLE ACIDITY	HYDROLYTIC ACIDITY	HORIZON	REMARKS
31	Pine-larch	5.2	6.5	37.5	A	Old burned area
73	Pine-larch	5.0	0.2	13.7	A	Thin forest
71	Pine-larch	5.8	0.9	70.5	A	Underbrush of cedar and pine
83	Pine-larch	4.5	4.5	119.0	A	Near 82
78	Larch-pine	6.5	0.5	90.0	A	Near 77
81	Larch-birch	6.2	1.1	87.0	A	
74	Larch-birch	5.4	9.0	129.2	A	
79	Larch-birch	3.8	46.6	133.5	A	Young stands
66	Larch-cedar	5.4	2.0	56.0	A	With A_0
60	Larch-cedar	4.5	4.0	90.0	A	
50	Larch-cedar	4.3	33.0	68.7	A	With fir
51	Larch-cedar	6.0	1.2	64.5	A	
51	Larch-cedar	4.2	29.2	51.5	B	
19	Cedar-poplar	4.0	18.5	117.2	A	
19	Cedar-poplar	4.9	2.5	18.2	B	
20	Cedar-poplar	4.4	10.0	24.3	A	
20	Cedar-poplar	4.3	31.2	67.2	B	
130	Poplar-cedar and fir	5.4	6.0	258.0	A	
64	Cedar-fir	6.1	2.0	116.0	A	With birch

TABLE 3

Phytopedological system

	COVER TYPE	pH	EXCHANGEABLE ACIDITY	HYDROLYTIC ACIDITY	CLASS INDEXES OF ACIDITY			CLASS
		1	2	3	1	2	3	
1	Fir-cedar	3.6	18.0	238.0	.....	.....	.....	.....
2	Fir-cedar	3.8	42.0	132.0	3.7	30.0	185.0	I
3	Cedar-larch	4.1	36.0	126.0	4.1	36.0	126.0	II
4	Fir	4.3	11.5	130.0	.....	.....	.....	.....
5	Cedar	4.4	12.5	128.0	4.3	12.0	129.0	III
6	Birch	5.6	1.5	87.0	.....	.....	.....	.....
7	Aspen	6.1	0.7	35.0	.....	.....	.....	.....
8	Pine-larch	6.3	0.5	33.0	5.6–6.5	1.1	11.0–87.0	IV
9	Poplar	6.6	2.0	26.5	.....	.....	.....	.....
10	Larch-pine	6.6	1.0	11.5	.....	.....	.....	.....
11	Pine	6.7	1.5	6.5	6.7	1.5	6.5	V

SUCCESSION OF ASSOCIATIONS AND THE PHYTOPEDOLOGICAL SYSTEM

All geographers, in treating of the succession of cover types, mention the pine, birch, and aspen as being first to follow fires, to grow on denuded soils, and cite them, in general, as a pioneer genus; while the cedar and fir are claimed by all to be species completing the process of the succession of cover types. The results given in table 3 show that the class indexes of acidity of these groups of cover types are found at the extreme points of the pH range.

From the viewpoint of the phytopedological system the fact, recorded by botanists-geographers, of the extraordinary vigor of the larch, which occurs together with representatives both of the first and last stages of cover-type succession, becomes quite clear.

Our table also shows a combination of the larch and pine, growing on neutral soils of pH 6.6, and the cedar, dwelling on very acid soils with a pH value of 4.1.

Certain authors, after claiming the aspen and birch to be the first species to follow forest fires, mention the larch as coming next and then the pine. Reverting to our system we note that the larch actually connects a class, comprising the birch and aspen, with that of pure pine.

Following the idea that the character of cover types determines the amounts of soil acidity, and that a gradual succession of cover types brings about an adequate alteration in pH values, we have attempted to establish, on the basis of analysis of horizon B, the trend of the said process in the past.

Let us examine, from this point of view, a few samples of soils:

NUMBERS OF SAMPLES	COVER TYPE	pH	EXCHANGEABLE ACIDITY	HYDROLYTIC ACIDITY	REMARKS
82	Pine-larch	6.4	0.3	19.2	On slope
83	Pine-larch	4.5	4.5	119.0	Dell

Sample 83 was extracted from the same place as sample 82 only on a little dell. A greater moisture and a thicker cover of moss on the spot from whence the sample was taken, tended to increase the acidity. According to our phytopedological system, sample 82 belongs to class IV, whereas sample 83, because of its hydrolytic acidity, may be ranked in class III; its exchangeable acidity, however, having outgrown the limits of class IV has, nevertheless, by no means attained the value of class III. Such a condition may be designated as IV → III, i.e. as a transitory stage towards an increase of acidity under the local influence of a lowering of the relief and of the process itself being not in its first stage. These will be intraclass soils of the phytopedological system.

Let us analyze a few more samples:

NUMBERS OF SAMPLES	COVER TYPE	pH	EXCHANGEABLE ACIDITY	HYDROLYTIC ACIDITY
71	Pine-larch	5.8	0.9	70.5
124	Cedar	4.2	15.7	293.0

Sample 71 should be, according to the nature of the cover type, classified in group 8; class IV and its exchangeable acidity actually correspond to indexes of that group. The hydrolytic acidity, however, is considerably higher and corresponds, approximately, to group 6. Evidently, this is the first stage of the alteration of the character of the soil, namely, a condition IV → IV, 6, that is, an increase of acidity beginning with an increase of its hydrolytic form.

Sample 124, according to its cover type, should belong to class III of our phytopedological system. The hydrolytic acidity of the sample is, however, considerably higher. Referring to the diary we find a remark, viz.: "admixture of fir." The fir belongs to class III, but in combination with the cedar it forms the highest form of class I acidity; therefore, this correlation of the given association and the soil may be designated thus: III → I. When it is considered that the pH values and the exchangeable acidity almost entirely correspond to class III, it should be recognized that we actually have only the initial stage of the process, which as yet has had no effect upon the exchangeable acidity.

An interesting example of the progression of soil acidity is obtained from a comparison of the two soil samples shown:

NUMBERS OF SAMPLES	COVER TYPE	pH	EXCHANGEABLE ACIDITY	HYDROLYTIC ACIDITY
128	Poplar	6.6	2.0	26.5
130	Poplar with cedar and fir	5.4	6.0	258.0

We have here extreme specimens of the phytopedological belt of cover type, and the nature of the effect of the cedar-fir association on almost neutral soils of the poplar association is made apparent even more sharply; namely, the increase of the exchangeable acidity in sample 130 being very small, its hydrolytic acidity, as compared to sample 128, gives a marked increase. The phytopedological sign for the condition of sample 130 will be as follows: IV → I.

All these examples are samples of *progressive forms of soil acidity*.

We should include in the regression forms the whole group of the cedar and larch association, because, in this case, we detect, together with the exchangeable acidity, which is inherent in the higher class, the hydrolytic acidity of the lower class.

It would be more correct to consider this group, not as an independent class, but as an intraclass group playing a part in the regression of soil acidity, which has attained its highest limits. A further progressive increase of acidity has become impossible because the biological, or perhaps even the physico-chemical limit, has been reached, and the larch promotes an inverse process. That this particular phase is the beginning stage of "deoxidation" can be seen from the fact that the exchangeable acidity has not lost the values of its initial class I, while the hydrolytic acidity decreases to class III. Dynamically this group may be designated thus: I → III.

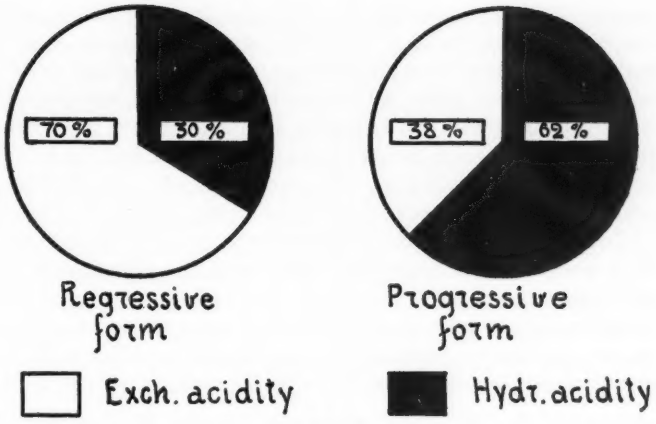

FIG. 1. CHANGES IN VARIOUS FORMS OF SOIL ACIDITY IN A CEDAR-PINE FOREST SOIL

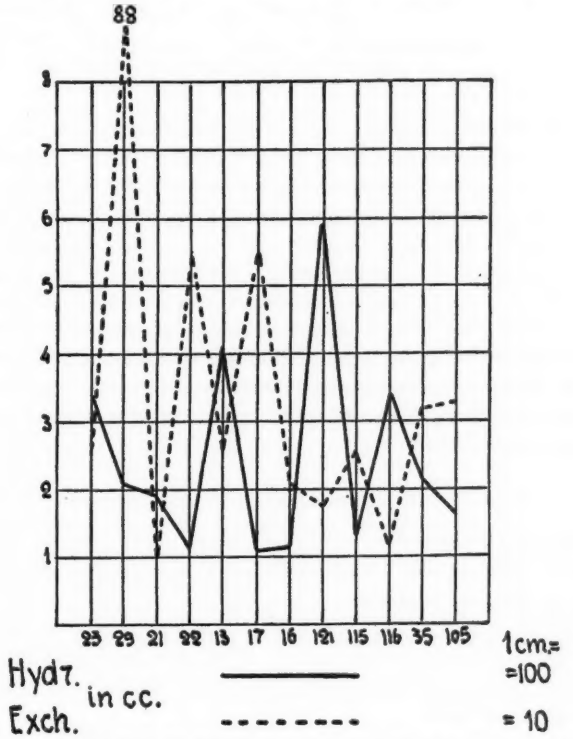

FIG. 2. PROGRESSIVE CHANGES IN HYDROLYTIC AND EXCHANGE ACIDITY IN THE SOIL OF A CEDAR-PINE FOREST ASSOCIATION

A closer perusal of figures obtained on the cedar-fir association, especially of their graphic rendering, has led to a very interesting observation. Both in our first work on the study of the acidity of taiga soils, and in the majority of data set forth in the present paper, we noticed a very distinct parallelism in the values of the exchangeable and hydrolytic acidities. Indeed, when soil samples were selected at random the exchangeable acidity was found to be directly correlated with the hydrolytic form. But, upon being selected in the same way, the cedar-fir association showed results diametrically opposite to those of the soil. All soil samples of the cedar-fir cover type, almost without exception, showed a decrease of the hydrolytic acidity when the exchangeable acidity increased, and vice-versa.

This extraordinarily interesting phenomenon prompted us to sum up the data on amounts of acidity contained in samples with prevailing exchangeable acidity, separately from those in which the hydrolytic form predominated.

Soil acidity of the cedar-fir cover type

	I CLASS	pH	EXCHANGEABLE ACIDITY	HYDROLYTIC ACIDITY
1	Progressive form	3.6	18.0	238.0
2	Regressive form	3.8	42.0	132.0

This table clearly sets out two trends in the dynamics of the acidity of class I, namely, the progressive and the regressive forms. When the exchangeable acidity is at its highest (42.0) a decrease of the hydrolytic acidity to values of class II (132.0) indicates regression. On the other hand, the value of the hydrolytic acidity (238.0) in another group of samples denotes an opposite process of a progressive accumulation of acidity, judging by the exchangeable acidity, which has not yet reached its highest point. In this manner, the process of an inverse "deoxidation" under a cover type of cedar and fir, takes place within the area of said cover type, both with the participation of the larch and without it. Most probably the regression of acidity in this, as well as in other cases, means that the given cover type begins to deteriorate after reaching its limits of growth ability.

CYCLICITY OF PHYTOPEDOLOGICAL RELATIONSHIP

Referring to bibliographical data, we wish to draw attention to one fact, which from our viewpoint is very important in establishing principles of the evolution of associate vegetation.

Sukache (38, 39) finds that the greater part of birch-aspen and pine associations are not permanent, but temporary. After fires they are succeeded by the fir, and after destruction of the latter, pine growth recurs, either directly after the fir or after the birch.

Dokturovsky (12) ascertained that nowhere have associations of birch or of larch-aspen-birch any special herbaceous growth peculiar to them. It is for

the major part a mixture of specimens of pine, fir, meadow, and other associations, which indicates their temporary, transition character.

Borovikor (5) found that the area of ancient taiga (Siberian vast forests) of the Enissey province (cedar-fir) was almost entirely substituted by pine forests, as a result of fires. He describes such a consecutive succession as follows: Following a fire, when all vegetation, including herbaceous species and moss growth, is destroyed, the first to spread are the aspen and birch and next the larch and pine. Eventually the pine supplants all other species, leaving individual specimens of the larch, birch, and aspen. At this particular time taiga specimens, namely, the fir and cedar, recur.

Kouznetsov (27) states that the larch is to be found in any type of forest, including pine groves and the fir-cedar associations. The author finds that the groves are displaced by taiga species, through the larch, which eventually develops into an association of larch-fir and cedar.

M. Iliin considers that the birch and aspen are first to capture land after fires. The aspen occurs on more humid soils; the birch, on those more dry.

Thompson (40), after analyzing the pollen of 16 lake and swamp profiles, established the succession of cover types for the entire period after the ice-age in Esthonia. He distinguishes the following periods:

The birch prevails, pines and willows still occur. The fir is absent.

The pine prevails instead of the birch, the latter attains a dominant position on very fertile soils only; it is less widely distributed, however, than the pine. The fir is absent.

Broadleaf forests (elm, linden, oak) are prevalent. The fir appears.

Broadleaf types recede. The fir attains its first maximum distribution.

Broadleaf cover types begin to vanish. The fir definitely invades the whole country.

In conclusion, Thompson remarks that in most upper zones the fir again recedes and the pine and birch play a more prominent part once more.

In comparing this consecutive succession (birch-pine-fir-birch), covering a period of many thousand years of forest life in Esthonia, with the aforementioned data submitted by Russian botanists in regard to the succession of forest associations after comparatively recent fires in Siberian forests (birch-larch-pine-fir-birch), the affinity of both these processes, which differ in regard to the range of time and place, suggests itself.

There is a definite sequence in the succession of forest associations. Forest fires, which have become more frequent since the appearance of man, tend to increase a rapid succession of forest associations, but do not interfere with the consecutive order of their occurrence.

As a rule the birch appears first and the further succession proceeds in two directions, namely the birch is either again directly succeeded by the cedar and fir, or it is first supplanted by the pine, which is followed by a return of the original taiga type. In other words the succession of cover types rotates within a small and a large circle.

If we apply this idea to the theory we are developing it will ensue that the birch may create such values of soil acidity as will be in conformity with the

requirements of the cedar and fir types, provided conditions of soil moisture are especially favorable. Under less favorable conditions the birch restricts the soil reaction to certain limits, which do not, however, attain minimums required by class I associations. This process is completed by the pine.

We have, however, to deal with the following situation: the succession of the birch by the pine in the phytopedological system is not a process of approaching, but rather of drawing away from, that condition of soil reaction which corresponds to the cedar-fir class.

The established opinion that a certain vegetation association requires identical soil conditions irrespective of its age is contradicted by the mere fact that associations such as cedar-fir, which in their mature state withstand especially high amounts of soil acidity, are reproduced under cover of pine and birch associations, which grow on soils having a reaction close to neutral.

We believe that after the soil supports a certain association for a long time, its reaction represents a final result as to limits of its effect upon the soil. These are extreme conditions which a given association can withstand and are not, by any means, always optimum conditions. Therefore, the expression generally used, that such an association "prefers" such soils, calls for a very serious correction. In the majority of cases it would be more correct to say that such an association "withstands" such soil conditions.

From this point of view we must assume that the fir and cedar are reproduced on soils with a neutral reaction and, with age, greatly increase the acidity; whereas the pine dwells on acid soils, neutralizing the reaction. Therefore the highest points of alkalinity for the pine and of acidity for the cedar and fir, according to our phytopedological system, should not be understood as the most favorable, optimum reactions for their "growth," but as a limit of alkali content allowing the "residence" of the pine and the limit of acidity for the "residence" of the cedar and pichta.

Optimum conditions of "growth" for the pine are to be found, in a literal sense of the word, in class I of the cedar and fir; whereas for the cedar and fir, optimum conditions exist in class V of the pine, which is in complete conformity with the aforementioned consecutive succession of these associations.

Sukachev (38, 39) states that the birch, oak, and probably the majority of broadleaf types are not, as a rule, reproduced under their own cover. Should optimum conditions of growth exist where an association grows, this phenomenon would contradict itself. It becomes clear, however, if our opinion, as set forth, is recognized as correct. In confirmation of this theory we can mention data obtained by Kouznetsov (27), who studied the artificial planting of pine in Western Siberia on chernozems, solonetz, and podzols. He found that pines planted on solonetz or slightly podzolized chernozems, perished. *He noted the most vigorous growths of pine on podzols* (7.3 m. elevation), the next vigorous on chernozems (5.6 m. elevation), and the weakest on solonetz (3.4. m. elevation). The bulk of the pine trunk on solonetz is almost 7 times smaller than that of a tree trunk on podzols.

Bearing in mind that soils on which mature pines generally occur are neutral and saturated with bases, we should anticipate a reverse phenomenon, provided we acknowledge that soils on which a certain association grows have a constant reaction. Hence, the pine begins its development on unsaturated, acid soils, and during its life cycle brings about a decrease in the acidity of the soil. Referring to the succession of the oak by the fir, Morozov (33) states that a litter of fir needles forms an acid humus, and a litter of oak leaves—a mild humus; and as the oak apparently is not reproduced under its own cover but only under that of the fir, we are dealing with an analogous instance of the succession of two types belonging to extreme classes of the phytopedological system.

Different genera differ in the nature and extent of alteration of the reaction. Such types as the larch and probably the fir and cedar may serve as examples of wider changes; and the birch—as one of restricted limits of acidity, within which they can possibly exist. We have given an example of a direct succession of the poplar (class IV) by the cedar and fir (class I). Hence, the alteration of soil reaction may be produced mutually by two types, or by a consecutive succession of several types, within a small and a large circle.

We believe that in various soil requirements of young and mature plants lies the solution of a number of phenomena which take place in forest life, and, in particular, in the mutual substitution of two types in the course of the succession of associated cover types. One of these, by providing remains of vegetation prepares the soil for the growth of young species of another genus, which in its turn, after having attained a dominant position, creates soil conditions imperative for the reproduction of the first genus. The phytopedological system is cyclic and is well balanced biologically.

FOREST LITTER AND HUMUS AND THEIR RÔLE IN FOREST REVEGETATION

Our object is not to discuss at length the very complicated question of the structures of soil humus. We shall quote only the most characteristic recent theories. Waksman's theory occupies the first place. He uses the word *humus*, rightly, only in quotation marks. By a systematic study of the decomposition process of various remains of vegetation, he proved that the so-called humus does not comprise any specific "humus" matter, but is composed of ordinary components, such as cellular tissue, lignins, and bacteria. In coöperation with other authors he found that the rapidity and the character of the decomposition of vegetative refuse, and consequently of the humus, depend first and foremost upon the nature and the age of the plant (41).

Pronevich (35), on studying the acidity of forest litters, gave the values shown in table 4 for different cover types.

We did not use for our studies pure needles or leaves, but the actual forest litter collected at one particular time and from soils under study. This resulted, therefore, in considerable fluctuations in the acidity values contained in litters of different cover types. However, our data show that the characteristics of

forest litters of diverse cover types differ, hence the further process of the litter's decomposition together with its final effect must needs differ.

TABLE 4

Acidity of needles and leaves

COVER TYPE	HORIZON A	HORIZON B
	pH	*pH*
Picea excelsa	4.3	4.6
Pinus silvestris	5.1	5.6
Betula pubescens	5.7	6.0
Acer platanoides	6.1	6.3
Tilia cordata	6.1	6.3
Alnus incana	6.4	6.6
Populus tremula	7.0	...

TABLE 5

Acidity of horizon A_0 of forest soils, Baikal District

NUMBERS OF SAMPLES	COVER TYPE	pH	EXCHANGEABLE ACIDITY	HYDROLYTIC ACIDITY
15	Fir-cedar, pure fir, and pure cedar	3.7	49.2	253.3
14		3.4	73.0	509.3
36		4.1	15.5	201.5
126		5.7	3.0	146.0
117		4.8	27.0	280.0
18		4.7	16.5	275.0
8		3.8	14.0	375.0
17		5.0	4.0	169.0
47		4.1	14.3	144.7
125		4.7	5.0	220.0
21		6.4	14.0	276.0
22		5.9	14.0	276.0
29		3.8	30.5	356.0
Horizon A_0, mean		4.6	21.0	265.0
Horizon A, mean		4.1	18.0	146.0

TABLE 6

Acidity of horizon A_0

NUMBERS OF SAMPLES	COVER TYPE	pH	EXCHANGEABLE ACIDITY	HYDROLYTIC ACIDITY
75	Aspen	6.2	2.0	14.0
54	Aspen	6.5	3.5	55.0
128	Poplar, willow	6.7	2.0	26.5

It should be noted that while the exchangeable acidity of the forest litter and of horizon A may be considered equal, the hydrolytic acidity of the forest litter considerably exceeds that of horizon A, underlying it. Hence, the forest

litter affects the trend of the soil formation process through the medium of the hydrolytic acidity it creates. This is in conformity with the aforementioned effect on the soil of the organic matter contained in stable manure.

On comparing values of the exchangeable and hydrolytic acidities, in accordance with our phytopedological theory, we must recognize that we have a total progressive degree of acidity for the given samples.

The acidity of the aspen and poplar litter layers is comformable to the character of the effect upon the soil and to the place these cover types occupy in our phytopedological system.

We have purposely set forth in table 7 various cover types having the larch as their associate member. This plant is one of the most interesting from a phytopedological point of view. It is connected with soils fluctuating from 3.2 to 6.7 pH, and of hydrolytic acidity fluctuating from 12.0 to 457.0. Such an exclusively indifferent attitude of the larch toward the soil reaction, permits its incidence in any and all forest associations and it probably plays the part of a phytopedological "buffer." By discussing the effect of A_0 on A we have

TABLE 7

Acidity of Horizon A_0

NUMBERS OF SAMPLES	COVER TYPE	pH	EXCHANGEABLE ACIDITY	HYDROLYTIC ACIDITY
65	Pine-larch	6.7	1.0	46.2
79	Pine-larch	6.6	1.5	12.0
74	Larch-birch	5.4	9.0	129.0
50	Larch-cedar	3.2	20.0	475.0

raised a new question, that of a corresponding effect of horizon A on B. Any changes which have taken place in the character of surface vegetation must needs be reflected, by means of a consecutive effect, on all horizons. And, very likely, lower horizons may tell us more about the past condition of their surface vegetation than upper horizons, which have just been formed. Considering horizon B to be a "paleontological" formation, we shall attempt to apply this viewpoint to data we have on hand.

NUMBERS OF SAMPLES	HORIZONS	pH	EXCHANGEABLE ACIDITY	HYDROLYTIC ACIDITY	COVER TYPE
51	A	6.0	1.2	64.5	Larch
51	B	4.2	29.2	51.5	Cedar

We picture the evolution of the given sample's soil formation process and the character of the participation therein of cover types, as follows:

In the past (see horizon B) this soil belonged to a higher phytopedological class than is seen from horizon A. The exchangeable acidity of horizon B—indubitably of a more ancient

origin than horizon A—is equal to the index of the cedar-fir association, i.e. to class I; at the same time the hydrolytic acidity recedes to class IV. Such a divergency speaks for the invasion of an association having lower indexes of acidity, and, as is usually the case, the hydrolytic acidity is first to diminish.

Horizon A may be ranked in the fourth phytopedological class, in accordance with values of its phytopedological indexes. Hence, in this case, we witness a completed process of the invasion by the larch of areas where the cedar formerly prevailed. This fact is supported by comparative data referring to the condition of forms of acidity of horizons A and B.

Let us make a few more excavations with a "paleontological" object.

NUMBERS OF SAMPLES	HORIZONS	pH	EXCHANGEABLE ACIDITY	HYDROLYTIC ACIDITY	COVER TYPES
19	A	4.0	18.5	117.2	Cedar-poplar
19	B	4.9	2.5	18.2	Cedar-poplar
20	A	4.4	10.0	24.3	Cedar-poplar
20	B	4.3	31.2	67.2	Cedar-poplar

Sample 19 in horizon B bears a convincing proof of the fact that the poplar dwelt here in the past, as all indexes of acidity of the given horizon are close to the normal indexes of class IV. Horizon A of this sample, however, even at this point, bears indexes of class III, showing an almost complete invasion by the cedar of the poplar. This may be designated as IV ↑ III.

Sample 20 illustrates an opposite phenomenon. In this case horizon B shows a greater acidity than horizon A; its exchangeable acidity pertains to class I, but a considerable decrease of hydrolytic acidity, as compared to the normal value of class I, testifies to its regressive movement having begun. This diagnosis is confirmed by examining horizon A, where the exchangeable acidity pertains to class III and the hydrolytic to class IV, as even in this case the decrease of hydrolytic acidity values, as against the normal value of its class, testifies to the beginning of a transition movement from class III into class IV. In other words phytopedological indexes of both horizons show an invasion of the cedar by the poplar. This phase will read: III ↓ IV.

These samples are of special interest because they represent, for the same type of association, inverse trends in the dynamics of acidity for each horizon. And, if figures of the acidity of these samples were to be considered from a descriptive point of view, they would only testify to an absolutely promiscuous distribution of all forms of acidity in each horizon even under the actual influence of one particular cover type. We should have been compelled to acknowledge, in regard to sample 19, that the podzol horizon rests on the surface of the soil.

Only a physiological outlook on facts has enabled us to understand processes taking place in the given samples, to determine the stage at which their development has been checked at this particular time, and even to foretell their future trend.

PHYSIOLOGY OF SOIL PROCESSES

The studying of soil from a physiological point of view has necessitated a few adjustments in the understanding of processes of horizon formation, dealt with in literature by the Russian school of soil scientists.

Soil horizons of the classical Russian school of pedology are a dead matter to the author in his capacity of physiologist. Examples discussed in the foregoing show that soil horizons are living biological formations, individually outlined, fighting for their existence, perishing, and regenerating. They bear traces of these processes as paleontological impressions.

If pedology studies horizons as morphological formations, the physiology of the soil will study bio-horizons, i.e. horizons still retaining the character of the vegetation which has formed them. The life of the soil, its history and relationship to the vegetation, its death and regeneration are the points which we will be looking for in bio-horizons of the soil.

The parent stratum, i.e. horizon D according to the nomenclature of morphologists-pedologists, does not lie in the depth of the soil profile but on its very surface. It is designated in soil science as A_0. Its character determines the character of further alterations in lower horizons, i.e. their physiology. Therefore, the most variagated subsoils may become the basis for the growth of most various forests. The physico-chemical condition of soil bio-horizons is in strict conformity with a definite type of vegetation which forms A_0.

The author has given a rough outline of a phytopedological classification in which the plant and soil are embodied in definite classes, each class having definite indexes of average normal conditions of correlation of the plant and soil.

Examples were given of the dynamics of phytopedological processes, and methods of determining the phase into which the said process has entered together with its trend were described.

In this case, however, the author has made use of but a few of the soil properties. Later, when physiological methods are applied to other soil properties our understanding of physiological processes in the soil will become clearer. Therefore, if questions of soil physiology will attract as much attention as do questions of soil morphology, the author, as a physiologist, will deem his purpose achieved.

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SOLUBILITY OF THE SOLID PHASE OF SOIL IN WATER

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Many investigators have studied the chemical action of water on minerals and rocks. Numerous laboratory investigations have been made on soil nutrients soluble in water. The action of water and salt solutions on diabase, porphyry, and silt loam was studied by Dietrich (2). Gedroiz (5, 6), changing the ratio between water and soil, investigated the solubility of soil compounds of saline and non-saline soils. The influence of the time of interaction and of the volume of solvent was studied by Zacharov (11). The same method of investigating the solubility of the soil combinations had been proposed formerly by Saidel (9). Vesterbergs (10), for the same purpose, applied three successive water extracts. Mitscherlich (8) studied the solubility of the soil in water saturated with CO_2.

The comparative study of soil solutions and water extracts may be considered as a kind of investigation on the solubility of soil compounds (1, 3, 4).

Water as a solvent of soil in comparison with other reagents has some advantages. In humid regions, water or dilute salt solutions are the medium of soil formation, plant growth, and microbiological activity. Therefore water applied as a solvent furthers the study of the processes of weathering, podzol formation, hydrolysis, and decomposition of the soil compounds in natural conditions. Besides, the influence of secondary accessory reactions from water extract is less than from other solvents.

The action of water on the soil consists in solution, hydrolysis, and decomposition of the soil compounds. In obtaining water extracts, the water acts first on easily soluble salts (nitrate, chloride, and sulfate of alkali metals). The salts of this type are usually dissolved in soil solutions and the water extracts them, even when the ratio of water to soil is small. The soil of humid regions does not contain many easily soluble salts. But under the influence of fertilization and tillage (fallow fields) the salt contents may increase to as much as 0.1 per cent. If the quantity of easily soluble salts in a soil is small and the soil does not contain carbonates and gypsum, the main action of the water is not solution but hydrolysis and decomposition of the composite soil compounds.

It is well known that minerals under the influence of water lose their bases and turn into SiO and R_2O_3 as final products of decomposition. The primary minerals (hornblende and others) probably being found in the soil, evidently

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react with water only in a colloidal state of dispersion. The theoretical principles of the reaction between the water and the colloid materials of the soil will be discussed further.

Our investigations were made in order to show the influence of various volumes of water on the solubility of the difficulty soluble soil compounds. For the investigations podzol and chernozem soils were taken at experiment stations of U. S. S. R. A brief description of these soils follows:

I. South chernozem of Kuban Experiment Station, 10 years uncropped, adsorbtion capacity 0.64 per cent Ca.
II. Chernozem of Kharkov district, virgin, adsorbtion capacity 0.77 per cent Ca.
III. Chernozem of Sumy Experiment Station (Ukraine), adsorbtion capacity 0.60 per cent Ca.
IV. Gray forest soil of Poltava, virgin, adsorbtion capacity 0.44 per cent Ca.
V. Podzol formed on marl of Viatka Experiment Station, uncropped, adsorbtion capacity 0.25 per cent Ca.
VI. Podzol of Engelgardt's Experiment Station, virgin, adsorbtion capacity 0.10 per cent Ca.
VII. Podzol of Experiment Field of the Agricultural Academy (Moscow), well-manured, uncropped, humus 1.5 per cent, adsorbtion capacity 0.17 per cent Ca.

These soils, taken from humid and subhumid regions, were free from carbonates and gypsum. The experiments were divided into two series:

1) ratio $\frac{\text{soil}}{\text{water}}$ ..... 1:1, 1:4, 1:10, 1:20, and 1:100
2) ratio $\frac{\text{soil}}{\text{water}}$ 1:4, 1:8, 1:16, 1:32, 1:64, 1:128

When the volume of water was small $\left(\text{ratio } \frac{\text{water}}{\text{soil}}\ 1:1\right)$ we obtained the liquid for the analysis by pressure in a little wine press. The water extracts were obtained by mechanical shaking for 10 minutes and filtering through an extra hard filter (602 Sch. und Schül). The first portion of the filtrate was discarded. The quantity of the electrolytes in the filtrate was determined by measuring the resistance on the Kohlrausch bridge at 18°C. The results of the first set of experiments are given in table 1, and of the second, in table 2.

These results prove that with the increasing of the masses of the solvent the quantity of soluble electrolytes increases though not proportionally.

It has been pointed out that the action of water on a non-saline soil consists mainly in first, solution of a small quantity of the easily soluble salts, and, second, in decomposition and hydrolysis of the soil colloidal material.

From a chemical point of view, the colloidal material of the soil—the adsorbing complex—may be considered as a combination of weak acids and strong bases. Michaelis (7) defines these compounds as saloid—heterapolaric chemical combinations insoluble in water and dissociated only on the surface. As a result of the dissociation on the surface of the soil particles there is formed a double electrical layer with numerous cations in the outer and one compara-

tively huge anion in the inner part of it. The saloids of the soil are more or less stable depending on the hydration of the cations.

TABLE 1

The quantity of the electrolytes in milliequivalent in kilogram absolutely dry soil

Values observed and calculated by equation $x = y\sqrt{V} + a$

SOILS	RATIO SOIL : WATER				
	1:1	1:4	1:10	1:20	1:100
Chernozem (I):					
Observed values	0.81	2.99	5.16	7.98	17.54
Calculated $y = 2.03$	0.81	2.84	5.19	7.85	19.07
Gray forest loam (IV):					
Observed values	1.17	2.13	3.86	....	11.65
Calculated $y = 1.12$	1.17	2.99	3.60	....	11.27
Podzol (V):					
Observed values	2.25	2.63	....	3.25	5.48
Calculated $y = 0.34$	2.25	2.59	....	3.43	5.33
Podzol (VI):					
Observed values	0.72	1.02	1.12	1.48	2.02
Calculated $y = 0.21$	0.72	0.94	1.18	1.46	2.63

TABLE 2

The quantity of electrolytes in milliequivalent in 1 kilogram dry soil

The values observed and calculated by equation $x = y\sqrt{V} + b$

SOILS	RATIO SOIL : WATER					
	1:4	1:8	1:16	1:32	1:64	1:128
Chernozem (IV):						
Observed values	4.47	5.75	7.97	10.23	13.70	19.07
Calculated $y = 1.57$	4.47	5.76	7.61	10.21	13.89	19.38
Chernozem (II):						
Observed values	2.35	2.94	3.49	.....	6.70	8.49
Calculated $y = 0.68$	2.35	2.91	3.71	.....	6.43	8.81
Podzol (VII):						
Observed values	1.14	1.18	1.19	1.28	1.48	1.55
Calculated $y = 0.039$	1.14	1.17	1.22	1.28	1.37	1.51

When the quantity of easily soluble salts in the soil is small and the non-colloidal minerals dissolve slowly, the influence of water on the soil consists mainly in the reaction between the water and the colloidal complex (saloids). The hydrolysis of these saloids is similar to that on chemical components of

strong bases and weak acids. Ostwald proved that the molecular electrolytic conductivity of the slightly dissociated binary electrolytes increase as the square root of the volume of the solvent. The formula of dissociation can be figured as follows:

$$\frac{a^2}{(1-a)V} = K$$

where a is the dissociated part of the molecule and V the volume of the solution. As the dissociation of the saloid is very small, a may be regarded as 1, then $\frac{a^2}{V} = K$, from which $a = K\sqrt{V}$.

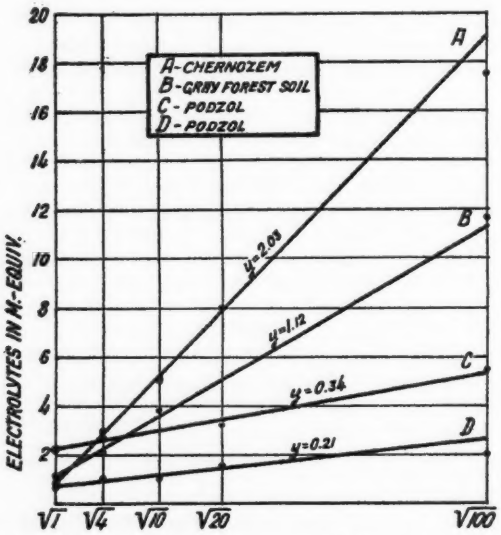

FIG. 1. SOLUBILITY OF THE SOIL COMPLEXES IN DIFFERENT SOIL TYPES

This formula, proposed by Ostwald only for cynare electrolytes was proved true also for the weak polybasic acids (fumaric, maleic, and others). Their dissociation proceeds according the equation $AcH_2 = A_cH + H$.

If we suppose that the dissociation of the fine colloidal material (saloid) runs similarly to the dissociation of the dissolved combinations, the interrelation between the quantity of the electrolytes extracted from the soil and the volume of the solution must follow the equation shown. The dissociation of many other non-colloidal combinations of the soil (compounds of strong acid and weak bases and the contrary) must follow the same rule.

The results of these investigations are represented by figures 1 and 2. The quantities of electrolytes are shown on the ordinate axis and on the abscissa—

the square roots of the ratio, soil to water. Evidently the connection between the quantity of electrolytes extracted from the soil and the volume of the water can be expressed by an irrational algebraic function $x = y\sqrt{V} + b$, where, x represents the quantity of soluble electrolytes in milliequivalents in 100 gm. absolutely dry soil, V the ratio between the volume of solvent and the weight of the soil, b the quantity (in milliequivalents) of the easily soluble salts extracted from the soil by small volume of water (ratio 1:1 or 1:4), y constant.

The calculated values x and y for each soil are represented in tables 1 and 2. The diviations of the observed and calculated values are within limits of the

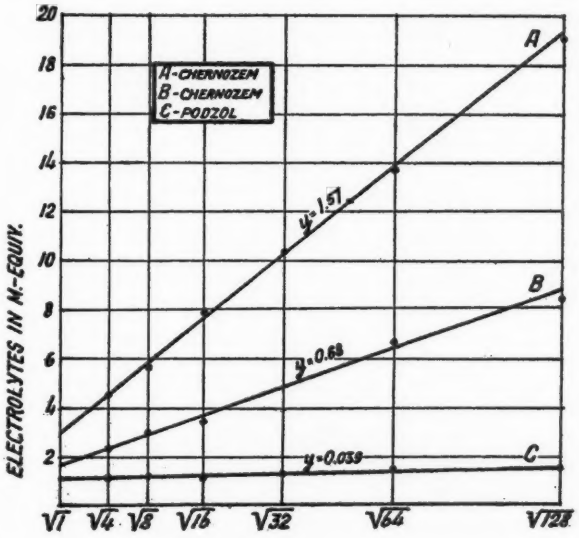

FIG. 2. SOLUBILITY OF THE SOIL COMPLEXES IN DIFFERENT SOIL TYPES

errors of determinations. The values of the constants y for the chernozem are: 2.03 (Kuban), 1.54 (Sumy), 0.68 (Kharkow). The constant for the podzol soil fluctuates from 0.04 (well-manured soil) to 0.20 and 0.34, and the constant for the gray forest soil of Poltawa region = 1.12. In general the slope of the straight lines for the chernozem is more steep.

The position of the first point on the straight line is more or less accidental; it shows the quantity of easily soluble salts of the soil. The position of the other points will be determined mainly by the quantity of the soil colloidal substance, by the composition of the adsorbed bases, and partly by the solubility of the non-colloidal compounds of the soil. Hence the solubility in water of soil (free from carbonate and gypsum) is a definite property of the soil colloidal state.

If the solubility of the non-colloidal compounds is disregarded a close connection between the soil colloidal complex and the quantity of electrolytes in water extracts will be noted in the non-saline soil. We compared the quantity of electrolytes in water extracts (1:100) and the adsorption capacity of the soils in humid regions of U. S. S. R. The data are shown in table 3. Some connection between quantity of soluble electrolytes and adsorbed bases can be found in this table, but this relation is by no means quantitative.

The action of water on the adsorbed bases can be explained in another way—by the action of H from the dissolved CO_2 in water on the soil adsorbed bases.

TABLE 3

Electrolytes extracted by water (ratio 1:100) and adsorption capacity

SOILS	ADSORPTION CAPACITY IN M.E. IN 100 GM. ABSOLUTELY DRY SOIL	THE QUANTITY ELECTROLYTES IN M.E. IN 1 KGM. ABSOLUTELY DRY SOIL
Podzol VI	5.25	2.02
Podzol VII	8.60	4.57
Podzol V	12.3	5.48
Gray forest soil IV	22.1	11.65
Chernozem VIII	29.1	16.07
Chernozem I	34.1	17.53
271	17.0	11.0
189	20.25	7.8
193	22.9	10.9
210	27.2	16.2
195	31.2	16.3
240	33.1	16.1
214	39.8	16.6
188	41.9	17.6
220	40.4	21.7
224	45.4	23.1

In this case the quantity of soluble salts in the extracts will vary in proportion to the amount of CO_2 in the water.

In order to obtain the approximate method of determining the adsorbed bases we endeavored to investigate the electropermeability of $HgCl_2$ soil extracts. The dissociation constant of $0.01N$ $HgCl_2$ is

$$\frac{[Hg]\,[Cl]^2}{[HgCl_2]} = 1.5 \times 10^{-14}$$

The reaction between $HgCl_2$ and the adsorbed bases of the soil may be represented as follows:

$$(Ac)\,Ca + HgCl_2 \qquad (Ac)\,Hg + CaCl_2$$

Thus the electropermeability of these extracts is mainly determined by the quantity of replacable bases in the soil. Our negative data probably were a result of the decomposition of $HgCl_2$ and the solvation of the non-colloidal substances. The salts of aluminum, iron, phosphate, and carbonate must hydrolyze according to the rules given in the foregoing. This reaction proceeds simultaneously with hydrolysis of the soil-adsorbed complex. We compared the solubility of our soils with that of certain difficultly soluble mineral compounds. We studied the solubility: of $Ca_3(PO_4)_2$, of phosphate rock from Podolia, and of Khibin apatite.[2] The work itself as well as the method applied to the analysis was the same as for soils. The data of these analyses are given in table 4.

TABLE 4

Solubility of apatite, phosphate rock and tricalcium phosphate in milliequivalent per 100 gm.

	RATIO				
	1:4	1:16	1:32	1:64	1:128
Apatite (Khibin):					
Observed	1.85	2.62	.....	3.84	4.92
Calculated $y = 0.34$	1.85	2.53	.....	3.89	5.04
Phosphate rock (Podzol):					
Observed	10.8	21.5	28.6	35.4	54.8
Calculated $y = 4.73$	10.8	20.3	28.1	39.2	54.4

	RATIO				
	1:5	1:10	1:40	1:80	
Tricalcium phosphate:					
Observed	70.1	80.7	109.1	138.6	
Calculated $y = 11.1$	70.1	80.4	115.4	144.5	

Under the given experimental conditions and within the range of the ratio of substance to water, from 1:10 to 1:100, rather close agreement of the calculated and observed values was obtained. The solubility of the phosphate from $Ca_3(PO_4)_2$ is much higher than that of the phosphate rock. The lowest solubility was shown by Khibin apatite. The values of the constant (y) successively were: for Ca_3PO_4 — 11.1, for Podolia phosphate rock 4.73, for Khibin apatite 0.34. The solubility of the relatively insoluble soil compounds was lower than that of phosphate rock. The constant for the chernozem soil solubility was higher than that of apatite. The value of y of podzol soil approached the constant of apatite solubility.

[2] The composition of Podolia phosphate rock: insoluble residue 3.72; P_2O_5 — 37.70; CaO — 48.78; CO_2 — 1.70; F — 2.5.

The composition of Khibin apatite insoluble residue — 8.4; P_2O_5 — 35.8 CaO — 47.43; F_2O_3 — 3.70; CO_2 — 0.0.

The apatite and phosphate rock were milled and passed through a 2-mm. sieve.

Therefore the expression $x = y\sqrt{V} + b$ is suitable for calculating the solubility of the phosphate minerals and other similar compounds. Thus by means of this equation, calculation of the solubility of soil phosphates and other compounds of the same type becomes possible. We worked out some of the data mentioned by Gedroiz (6) concerning the solubility of non-saline soil. The data on sodium carbonate and humus extracted from solonetz soil with subsequently increasing water volume are in full accordance with the values (shown in table 5) obtained by calculation. This agreement can be easily understood from a theoretical point of view, as sodium humus and carbonate are compounds of strong base and weak acid. The general amount of mineral residue extracted from the podzol soil by means of increasing water volume is similarly explained. The agreement was less close for the mineral residue of chernozem loam.

TABLE 5

Gedroiz's data

	RATIO									
	1:1	1:1.5	1:2	1:3	1:4	1:5	1:6	1:8	1:10	1:20
Solonetz:										
Observed	99	...	166	231	280	325	366	432	490	780
Calculated	99	...	163	231	280	325	361	430	490	727
Podzol clay:										
Observed	189	204	213	240	268	280	294	344	370	400
Calculated	189	204	219	242.0	269.9	279.1	294	322	346.0	441

The solubility in water of individual soil compounds (phosphate and others) must follow the aforementioned formula. Investigations along this line are being continued.

The investigation of the electropermeability of water extracts from the soil may be interesting from another point of view. It is known that the basicity of acids and to some extent their structure can be determined by the electropermeability of salts of polybasic acids. Hence the study of the electropermeability of water extracts may be a means of investigating the nature of organic and mineral colloidal matter of the soil.

SUMMARY AND CONCLUSION

The solubility of chernozem and podzol soils (free from carbonate and gypsum) in water with different ratios of soil to water (from 1:1 to 1:128) has been studied. The quantity of soluble compounds has been determined by electrolytic conductivity of the water extracts. Two series of experiments have been set up:

ratio of soil to water..... 1:1, 1:4, 1:10, 1:20, 1:100
ratio of soil to water..... 1:4, 1:8, 1:16, 1:32, 1:64, 1:128

For the tests the following soils were used: chernozem, podzol, and gray forest soil. The analysis of data reported in the paper leads to several conclusions. Between the volume of the solvent and the quantity of electrolytes exists a functional relation which can be expressed by the equation

$$x = y\sqrt{V} + b$$

where, x represents the quantity of soluble electrolytes in milliequivalents in 100 gm. absolutely dry soil, V the ratio between the volume of dissolvent and the weight of soil, b the quantity (in milliequivalents) of easily soluble salts extracted from the soil by a small volume of water, y constant.

The value of the constant (y) for chernozem fluctuated from 0.68 to 2.03, for podzol from 0.04 to 0.34. The observed and calculated data are shown in the tables 1 and 2.

The study of the solubility of phosphate minerals (apatite, phosphate rock) in water shows that the solution of these minerals to some extent follows the same rule. The constant (y) of the solubility of apatite was about the same as that of the podzol soil.

The data on sodium carbonate and humus extracted from solonetz soil with successively increasing water volume are in full agreement with the values obtained by calculation.

The investigation of the solubility of individual soil compounds in water is being continued.

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